- Whether armor may be patted down between test shots (which the standard prohibits) to reduce the ply separation (''bunching' caused by previous shots.
- The incidence and statistical significance of apparently random variations in outcomes of similar tests, and, if significant, their causes.
- Whether armor should be failed (as the standard requires) if a nonpenetrating test shot makes a crater deeper than 44 mm (1.73 in) in the material on which the armor is mounted; this is assumed to indicate inadequate protection from the impact of a stopped bullet.
- The protection afforded by the current standard against false or deceptive advertising or labeling (e.g., of armor as complying with the NIJ standard, when in fact it has not been tested for compliance).

In addition, the study was to investigate ancillary issues, such as the shape of the test fixture to which the armor is attached for ballistic-resistance testing and the choice of the backing material (inside the test fixture) against which the armor is placed to be shot.

BACKGROUND

Soft Armor and Hard Armor

Two types of armor are worn by police: soft armor and hard armor. Soft *armor*, designed to stop handgun bullets, is worn routinely by many officers. It is often worn in a sleeveless undergarment called a "vest" (see photo) but is sometimes incorporated into the lining of a jacket or other outer garment. It is designed to be inconspicuous, although a person intent on detecting it might discern it under light clothing at close range in daylight.

Hard armor is domed, often over soft armor, by police on special assignments expecting an unusual risk of rifle fire or stabbing. It maybe inconspicuous but is often quite distinctive: television viewers recognize it as the armor worn by SWAT (Special Weapons and Tactics) teams (see photo). Police call it "tactical armor' and generally find it too hot, heavy, or conspicuous for routine wear. It may include panels of sheet steel or titanium, perhaps coated or tiled with ceramic.

Most bullets that kill police officers are fired by handguns (see box D). Some soft, concealable body armor is designed to offer protection against the full spectrum of handgun bullets. Lighter, less expensive models offer protection against the most common handgun bullets.

Many officers are killed by shotguns firing shot or slugs; soft armor has apparently saved many officers from such projectiles.

Many officers are killed by rifles. Soft armor has apparently saved a few officers from carbine fire,[6] but hard armor is usually required to meet the NIJ or PPAA standard for protection from rifle fire.

Summary of NIJ Standard 0101.03

A Performance Standard

The .03 standard is a performance standard, not a construction standard. It does not specify the area of coverage, nor does it specify any material to be used in the armor. This permits and encourages technical innovation, including the development of materials and designs providing better ballistic resistance, greater comfort, or lower cost. However, some aspects of the standard were introduced specifically to provide stringent tests of likely weak points of Kevlar fabric armor, which at the time was almost the only type of concealable body armor marketed in the United States.

Certification of Compliance

NIJ Standard 0101.03 provides for the *manufacturer* to certify, on the label, that armor is of a *model* that has a type of ballistic resistance defined by the standard if *samples* of the same model have passed the test specified by the standard for that type of ballistic resistance, regardless of who conducts it. Such a test could be conducted by the manufacturer or by an independent ballistic laboratory under contract to the manufacturer. A manufacturer could truthfully certify a model of armor to comply with NIJ Standard 0101.03 even if it failed the test repeatedly before finally passing it. Partly because of this, a manufacturer's certification, by itself, may provide little assurance of design quality.

However, manufacturers (or any other interested party) may submit samples of a model of armor to NIJ for NJ-supervised testing by an NIJ-approved

[6] A carbine is a compact rifle that fires cartidges designed for rifles or pistols. Because of its short barrel, it does not accelerate rifle bullets to the velocity they would attain if fired from a longer-barrelled rifle.

Box D—Trends in Weapons and Ammunition Used in Assaults on Police

Jurisdictions all across America report an upswing, during the last few years, in the confiscation of guns of greater firepower, as measured by caliber, muzzle velocity (which increases with barrel length), magazine capacity, and rate of fire (e.g., fully automatic). These include so-called "assault rifles" and automatic pistols (see box E) that fire "high-energy" ammunition such as .357 Magnum, .44 Magnum, and 9-mm Parabellum (see box F). Officers feel they are more threatened by these guns than they were in the past. [102] Some blame the increase on the affluence of criminals involved in the drug trade; others see it as an unfortunate side effect of the largely successful campaign to ban the short-barreled, small-caliber handguns known as "Saturday night specials. "

Mysteriously, this trend toward long guns and high-energy handguns is barely perceptible in the guns actually used to shoot police officers. It may be that most of the increasingly numerous submachine guns seized were purchased for show or to shoot other criminals; with few exceptions—about one per year-they are not being used to attack police-at least, not yet. The few cases of their use against police-generally with no greater effect than a revolver—are highly publicized, which may inflate the perceived magnitude of the threat they pose.

The trend toward increased use of high-energy handguns in assaults on police, although slight, is real. Part of the increase is attributable to the issuing of .357 Magnum revolvers or 9-mm automatic pistols rather than .38 Special revolvers by many police departments responding to a perception (or projection) that their officers will face firearms similar to those they confiscate. However, about a fifth of all officers who are shot are shot with their own gun or their partner's, so an upgrade of the officers' own sidearms increases the threat they face and against which they are well advised to protect themselves.

SOURCE: Office of Technology Assessment, 1992.

independent laboratory and, if it passes, for certification of compliance by NIJ. NIJ's criteria for certifying compliance, which include the standard itself and a host of other memoranda, prohibit accepting armor of a model that has previously failed an .03 certification test.[7] TAPIC, to which samples must be submitted for NTJ-authorized testing and (if successful) certification, inspects samples and attempts to determine whether the samples are substantially the same as samples previously submitted under a previous model name.

Armor certified by NIJ is listed on NIJ's Consumer Product List, which is maintained by TAPIC. Consulting NIJs Consumer Product List is the only sure way to determine whether NIJ has certified compliance with NIJ Standard 0101.03; this cannot always be determined from the label. Some marketed armor is certified only by the manufacturer and not by NIJ.

Models and Styles of Armor

NIJ notes that "For the purposes of the . . . body armor certification procedures, the following definitions have been adopted:

A body armor MODEL is a manufacturer designation that identifies a unique ballistic panel construction; i.e., a specific number of layers of one or more types of ballistic fabric and or ballistic-resistant material assembled in a specific manner.

A body armor STYLE is a manufacturer designation (number, name, or other descriptive caption) used to distinguish between different configurations of a body armor product line each of which includes the same model of ballistic panel.

The distinctions between body armor model and style were established to eliminate the necessity of retesting a given body armor model for compliance with the NIJ Standard each time a manufacturer incorporates the model into [a] different style of armor. [145]

NIJ certifies the ballistic resistance of a model on the basis of ballistic testing of samples of the model in accordance with the standard; NIJ certifies the ballistic resistance of a style on the basis of inspection of a sample by TAPIC to determine that it does indeed contain a model of ballistic panel already certified to have the ballistic resistance claimed for the style. Thus all styles of the same

7 We distinguish between NIJ's certification criteria, which require one test according to NIJ Standard 0101.03 and have other requirements as well, and the ballistic test specified by the standard, which maybe performed for NIJ certification or for other purposes, such as manufacturer's certification of compliance or testing samples of certified models for quality assurance (commonly called "retesting").

Box E—Types of Guns

Firearms are classified according to barrel length as handguns or long guns; the latter include rifles and shotguns. Handguns and rifles (and some shotgus) are generally designated by their "caliber" and by the nature of their firing action.

The caliber is the inside diameter of the barrel. Thus .22s have barrels with an inside diameter of 0.22 inch, and that of "9mm" guns is 9 millimeters. Anomalously, .38 Specials have barrels with the same inside diameter as that of a .357-caliber revolver: 0.357 inches. While the .38 Special cannot fire the longer or "magnum" .357 ammunition, the .357 revolver can fire .38 ammunition.[1] The designation" .380" is used for automatics firing .38 caliber (i.e., .357 -inch) bullets from specialized cartridges. The "+P" designation appended to some .38 Specials indicates that the gun can withstand the high chamber pressure exerted by +P ammunition.

With the exception of the .410-caliber shotgun, a shotgun is measured by reference to a (now largely hypothetical) musketball-style lead sphere that just fits in the barrel: the "gauge" of the shotgun is the number of such balls one could make from a pound of lead. Therefore a smaller gauge number denotes a larger gun. The most common sizes of shotgun are the 12 and 20 gauges; if measured in inches these would be approximately .80 and .68 caliber, respectively. If .410 shotguns were measured in terms of their gauge, they would be 90 gauge. There also exist shotguns of gauges 28,16, and 10.

Other anomalies abound. For example, while the .30-06 and the .30-30 rifles use the same .308-inch diameter ammunition, the "06" of the former's designation refers to its year of adoption by the military, while the second "30" in ".30-30" refers to the (original) weight of the latter's powder load, in grains.

Actions are often designated "full automatic," "automatic," "semi-automatic," "autoloading," "double action," "single action," "bolt action," "lever action," and "pump." These terms divide the weapons according to what the firer must do to fire repeated shots. "Full automatic" weapons will fire continuously as long as the trigger is pulled back, until they run out of ammunition (or until they jam). "Semi-automatic," "double action," and "autoloading" weapons require a separate trigger pull for each shot. "Single action" weapons require "cocking" between shots; "bolt action," "lever action," and "pump" rifles and shotguns require operation of their bolt, lever, or pump between shots.

The terms "automatic" and "semiautomatic" are not always correctly used or understood. Regarding handguns, "automatic" is used in contradistinction to "revolver"; the Colt .45 M1911al (familiar for decades as the U.S. military's sidearm) is an "automatic" whereas the Colt .45 Peacemaker (of cowboy fame) is a revolver. "Automatic" handguns fire in the manner called "semiautomatic" for other guns: shots can be fired in rapid succession by repeatedly pulling the trigger, without any other action such as operating a bolt, pump, or cocking lever—but so do most modern revolvers. (Some products of the Ruger Arms company and the Colt Peacemaker, which appeared in 1873, do not.) Otherwise, "automatic" is properly used to describe "full automatic" guns, i.e. machine-guns: guns that will continue to fire as long as the trigger is depressed. (Most such guns have a "selective-fire switch," allowing the user to toggle between full automatic and semiautomatic modes of operation.) A submachinegun is a machine gun that fires pistol ammunition.

A "carbine" is a compact rifle. Attempts to define the term "assault rifle" for legal purposes have met with great difficulty because these guns differ from other semiautomatic carbines largely through styling, not functionality.

1 This can make it difficult to establish what type of ammunition was used in an assault, which makes reenactment problematical.

SOURCE: Office of Technology Assessment, 1992.

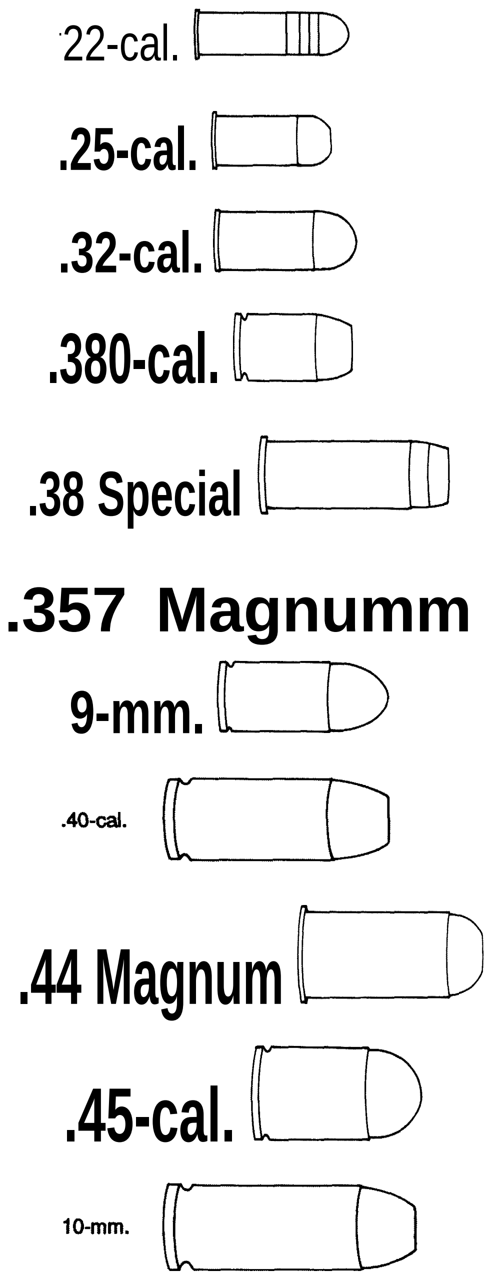
model are assumed to have the same ballistic resistance.

TAPIC considers garments differing only in color to be of the same style. Differences in the size or cut (i.e., shape) of garments would make them different styles, not different models, even though size and cut possibly affect ballistic resistance. Differences in stitching of ballistic panels (e.g., box stitch versus quilt stitch) would make the panels different models.

Types of Ballistic Resistance

The .03 standard defines six standard types of ballistic resistance for which armor may be tested and provides for custom testing for "special type" ballistic resistance. Each type is defined in terms of

Box F—ABCs of Ammunition, Bullets, and Cartridges



Pistol and rifle ammunition is described in terms of the diameter of the bullet, the length of the cartridge, and the shape and composition of the bullet. Shotgun ammunition is described in terms of the diameter (gauge or caliber) of the gun barrel for which it is designed, and by whether it contains a single bullet-like "slug," or if not, by the size of the shot or pellets it contains.

Bullet diameters are, of course, the same as the inside diameters of the gun barrels from which they are fired. The sizes and nomenclature of these were discussed in box E.

The length of the cartridge has a direct bearing on the amount of powder it can contain and thus on the velocity with which it can propel the bullet. "Mag-num' cartridges are longer than standard cartridges to contain more powder. Likewise, many handguns are chambered for .22 Long Rifle cartridges, which contain more powder than .22 "Shorts."

Bullets vary in shape, construction, and composition. The shape can range from the relatively pointed Speer bullet, no longer used in body armor testing, to the cylindrical "wad cutter" bullet optimized for the clean punching of circular holes in paper targets. The '' semi-wadcutter" shape is a compromise between the wadcutter and the typical domed bullet shape. 'Hollow-Point" bullets feature a small cavity in the nose, to create mushrooming after impact. Some controversy surrounds the question of whether nominally identical bullets differ sufficiently in shape to affect the outcome of armor tests.

Bullets can have full or partial metal jackets. A partial jacket, typically found on a hollow point bullet, leaves the nose of the bullet exposed. The jacket is typically made of copper, though copper-clad steel jackets are not unheard of. A "gas check" is a copper shield on the base of the bullet to keep the burning gunpowder from melting the base while the bullet is still in the gun.

Jackets and gas checks aside, bullets are normally made out of lead. The hardness of this lead is governed by the degree to which it is alloyed with other metals.

Some bullets contain harder metals, either in the form of steel balls cast into the lead or, in the extreme case, machined steel, brass, or even tungsten bullets coated with copper or Teflon. These bullets are designated "armor piercing." "Armor piercing" military rifle bullets, such as those used in testing Type IV armor, consist of a steel core covered by a full copper jacket. Some have lead bases or point fillers. The rare Teflon-coated bullets made of machined steel, brass, or

tungsten have gained notoriety far out of proportion to their number. Originally designed for use by police officers in shooting through cars, they received their "cop killer" nickname later, when soft body armor was introduced. They will penetrate soft body armor, but no armor-wearing officer has been killed by one.[1] The Teflon in itself confers no special armor-piercing properties, and is used merely to lessen the extreme barrel wear that would otherwise be caused by bullets made of such hard materials.

Shotgun loads range from birdshot loads containing hundreds of small pellets to the slug load, composed of a single bullet-like "slug." Buckshot lies between these extremes, with a shell containing a dozen or so pellets, depending upon the size of the buckshot. To make up for the lack of rifling inmost shotgun barrels, slugs themselves are typically rifled, i.e., cast with slanted grooves on their sides to impart aerodynamically the spin needed for stability.

1 Two officers were killed by such bullets in 1967, before the introduction of soft body armor into law enforcement use.

SOURCE: Office of Technology Assessment, 1992.

the type or types of bullets fried at panels of the armor to test its ballistic resistance (see table 1). Two types of handgun bullets are fired to test for Type I, It-A, II, or III-A ballistic resistance, which soft armor can provide. One type of rifle bullet is fired to test for Type III or IV ballistic resistance, which hard armor can provides

Each standard type of armor is expected to offer protection against the threat associated with it as well as against the threats associated with all other standard types of armor appearing above it in table 1. For this reason, the types of armor defined by NIJ Std. -0101.03 are often referred to as "levels," level Ii-A being presumably superior to level I, for example. However, a certification test for type II-A ballistic resistance would not actually test resistance to type I threats. In addition, an NIJ guide specifies other threats against which it expects armor of each standard ballistic-resistance level to provide protection (see table 2), even though the .03 test does not actually test resistance to such threats. [145]

Selection of Samples

The NIJ standard specifies that "Four complete armors, selected at random and sized to fit a 117 cm (46 in) to 122 cm (48 in) chest circumference, shall constitute a test sample. (Note: The larger the size, the more likelihood that all ballistic testing will fit on just two complete armors.)' In quality assurance, ''selected at random' usually means ''selected at random with uniform probability' '—i.e., sampling should insure that all units of the model should have the same chance of being selected to be tested. However, this is impossible if samples are selected for certification testing before production of the model has been discontinued. Typically samples are selected after only a few units have been produced; consequently, the sampling procedure does not guarantee that the samples are representative of

Table I—Types of Ballistic Resistance Defined by NIJ Standard 0101.03 in Terms of Bullets and Velocities Specified for Testing

Type	Bullet caliber and type	Bullet mass (grains)	Impact velocity[a] (ft/s)
I	.22 long rifle high-velocity	40	1,050
	.38 round-nose lead	158	850
II-A	.357 jacketed soft-point	158	1,250
	9-mm full metal jacket	124	1,090
II	.357 jacketed soft-point	158	1,395
	9-mm full metal jacket	124	1,175
II I-A	.44 magnum lead semi-wadcutter gas-checked	240	1,400
	9-mm full metal jacket	124	1,400
III	7.62 mm full metal jacket	150	2,750
Iv	.30-06 armor-piercing	166	2,850
Special custom		custom	custom

[a] Minumum velocity; the maximum velocity for a fair hit is 50 ft/s greater.

SOURCE: National Institute of Justice, 1987 [144].

8 The test procedure for ''special type'' ballistic resistance is the same as for standard types of ballistic resistance, except the person ordering the testing (e.g., a manufacturer) specifies the type and nominal velocity of the test projectile to be used. For example, a manufacturer could have armor tested for NIJ certification of Special Type ballistic resistance to a .45-caliber bullet, a 12-gauge rifled slug, or buckshot at a specified velocity, Special-type armor is not necessarily expected to protect against the threat associated with any other type.

Table 2—Types of Ballistic Resistance Defined by NIJ Standard 0101.03 in Terms of Guns and Ammunition Against Which Protection Is Expected

Type	Threat
I	.22, .25 and .32 caliber handguns, .38 Special lead round-nose
II-A	.38 Special high-velocity, .45s, low-velocity .357 Magnum & 9-mm, .22 rifles
II	Higher velocity .357 Magnum and 9-mm
III-A	.44 Magnum and submachine gun 9-mm
III	High-power rifle: 5.56mm, 7.62mm FMJ, .30 carbine, .30-06 pointed soft point, 12-gauge rifled slug
IV	Armor-piercing rifle bullet, .30 caliber (1 shot only}.

SOURCE: National Institute of Justice, 1987 [144] and 1989 [145].

yet-to-be-produced units of the model, particularly of smaller sizes.

Conduct of the Test

Armor to be tested is mounted on a flat block of inelastic backing material-typically modelling clay—to be shot. The impact velocity of each bullet is measured using a ballistic chronograph (see figure 2). If the bullet hits an appropriate point on the panel at an impact velocity within specified limits (see table 1), the impact is considered a fair hit. The test requires a fair hit in each of six specified areas on each panel in a specified sequence (see figure 3). Each shot must impact at least 3 inches from the edge of the panel and at least 2 inches from the closest point of impact of any prior shot.

In tests of Type I, II-A, II, or III-A ballistic resistance, four complete armors, typically including eight armor panels (four each front and back) are usually shot. Each ballistic element (front or back panel) is sprayed with water and then shot with test bullets of the first type, then another one is sprayed and shot with test bullets of the second type. This is repeated with unsprayed, dry samples. This requires a minimum of 48 shots per test: 2 element types (front and back) x 6 shots each x 2 types of test bullets x 2 wetness conditions.

If the velocity of a shot is too low and it does not penetrate the panel, or if the velocity of a shot is too high and it does penetrate the panel, the shot is repeated, aimed at least 2 inches from the closest point of impact of any prior shot. However, no more than eight shots (of one caliber) may be fired at any panel.[9] The armor cannot be certified if any fair shot penetrates.

After the first fair shot at each panel, the panel is removed from the backing and the depth of the crater (called the backface signature or BFS) is measured. If the BFS exeeds 44 mm or if the armor was penetrated, it fails; if not, the panel is replaced on the backing without filling the crater or otherwise reconditioning the backing material, and testing for penetration is resumed.[10] The standard prohibits adjusting a panel (e.g., patting it down) thereafter, unless it is reused for testing with a second type of bullet.

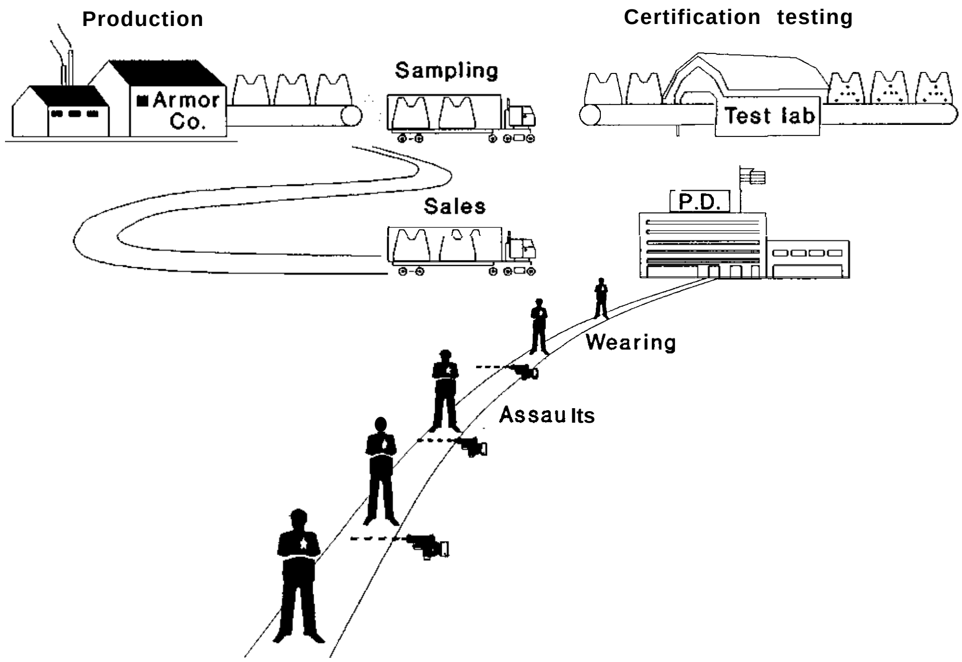
NIJ Standard 0101.03 specifies that armor be tested on a block of backing material at least 4 inches thick "and of sufficient length and width . . . to completely back the armor part to be tested. " The standard does not specify unambiguously that the backing must be flat, and in fact requires it to be built up to achieve contact with the armor when testing female armor with bust cups or when testing rigid armor for Type III or IV ballistic resistance. However, in practice, a flat surface is used in other cases.

Until recently, the testing of a whole armor garment with removable ballistic panels (the usual configuration) was precluded by the requirement that each ballistic element (e.g., panel) be tested separately. (Although the standard explicitly allows testing a whole armor garment if it is made in one part without removable ballistic panels, this may be precluded by the provision that requires the backing to be "of sufficient length and width . . . to completely back the armor part to be tested.") In a letter dated April 27, 1992, NIJ directed H.P. White Laboratory, Inc., that effective June 1, 1992, it should test samples for compliance with NIJ Stand-

9 To provide for contingencies, six complete armors (12 panels) must be submitted for a Type I, ~-A, II, or ~-A test.

10 NIJ Standard 0101.03 specifies that testing shall be continued after each BFS measurement if it is no greater than 44 mm, and after shooting six fair shots per panel if none penetrated. It neither requires nor prohibits continuation of the testing in other cases—i.e., after failures. However, NIJ has directed H.P. White Laboratory, Inc. (HPWLI), the only laboratory authorized to conduct testing for NIJ certification, to complete the testing despite disqualification of the armor.

Figure I—Certification That a Model of Armor Complies With the NIJ Standard Is Based on Inspection and Testing of Samples Submitted by the Manufacturer



SOURCE: Office of Technology Assessment, 1992.

ard 0101.03 by mounting the whole armor garment on a smaller clay block in a curvilinear frame (see photo)--a highly abstract mannequin.[11] The standard itself was not changed.

This summary does not cover all details of the standard; the interested reader is referred to the standard itself and to appendix A of this report for additional details.

Validity of the Test

The standard does not explain the rationale for its provisions but does refer readers to an NIJ guide that discusses the origin of the standard briefly and cites detailed reports of research considered by the drafters of the standard.

The standard specifies how to conduct a ballistic test of samples of a model of armor under controlled conditions, in order to measure properties of the samples (types of "ballistic resistance") that can reasonably be expected to be related to the protection that other samples of the same model will afford wearers in service. However, the details of the relationship are uncertain and disputed; no body of data reliably links performance in the lab with performance in service. This situation is common in consumer-product safety testing, but it leaves room for legitimate questioning of the meaning of passing the test.

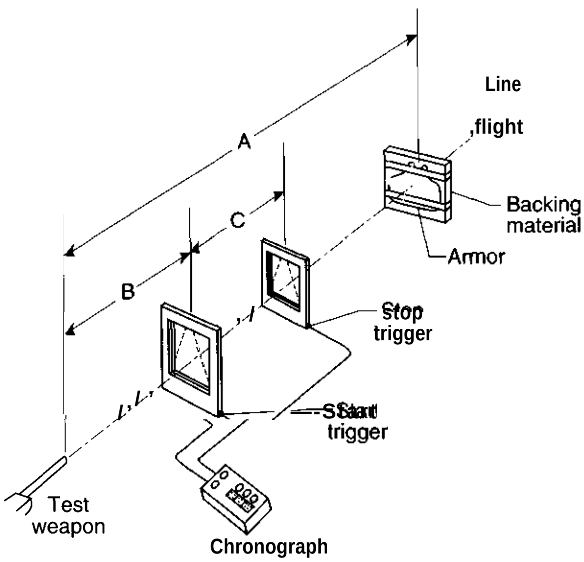
FINDINGS

Benefits of Wearing Armor

Body armor saves lives and could save more if worn more often by more officers. Wearing armor has saved about 10 to 30 sworn police officers from fatal gunshot wounds each year in recent years. The number saved each year would roughly double if all officers wore armor at all times. Wearing armor also saves officers from death or serious injury in other types of assaults and accidents, especially vehicle accidents. By industry estimates, armor has saved over 1,300 police from death or serious injury by firearms assaults (about 40 percent), other assaults (about 20 percent), and vehicle and other accidents (about 40 percent). [18]

[11] "Retesting" (testing samples of a model certified to comply with NIJ Standard 0101.03)" is to be done using the type of test fixture used in the certification test.

Figure 2—Instrumented Ballistic Test Range for Testing Armor as Specified in NIJ Standard 0101.03



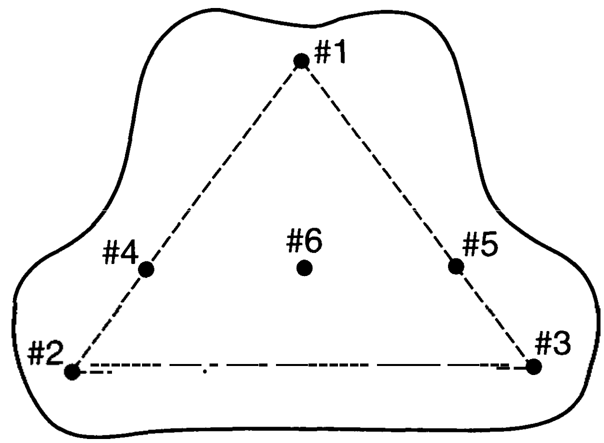
A -5 m for type 1, II-A, II, and II I-A armors; 15 m for type III and IV armors.

B -2 m minimum

C - Approximately 0.5 to 1.5 m

SOURCE: National Institute of Justice, 1987.

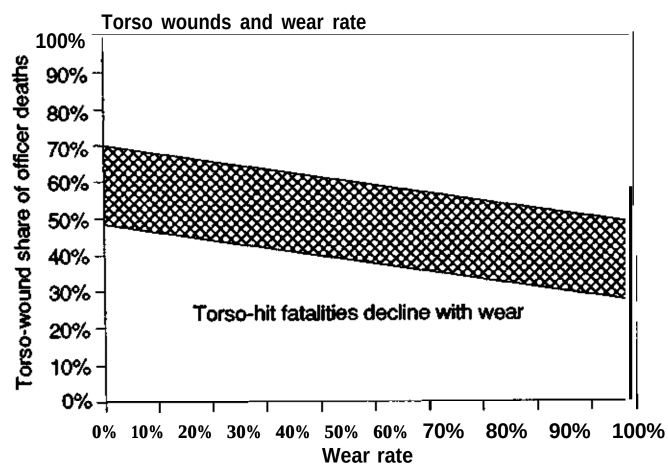
Figure 3-Sequence of Aim Points on Each Panel, as Specified in NIJ Standard 0101.03



All shots at least 7.6 cm (3 in) from any edge and at least 5 cm (2 in) from another shot

SOURCE: National Institute of Justice, 1987.

Figure 4—How Fatal Bullet Wounds in the Torso Would Decrease if the Wear Rate Increased



SOURCE: Office of Technology Assessment, 1991.

However, even universal wearing of armor would not save officers from fatal gunshot wounds in unprotected parts of the body or from some guns and ammunition more powerful than those the armor was designed to protect against (see figure 4).[12]

Factors Influencing Wearing of Armor

Police departments can promote the wearing of armor by

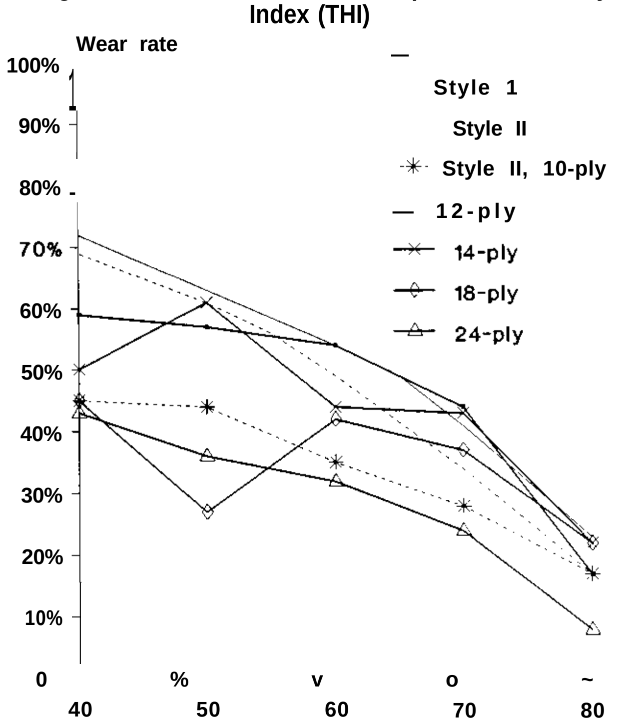
1. **purchasing and issuing it or reimbursing officers for purchasing their own armor,**
2. **ensuring that it fits,**
3. **encouraging or requiring officers to wear armor when on duty,**[13]
4. **ensuring that chiefs and other supervisory officers set a good example by wearing armor, and**
5. **instructing officers in the donning and laundering of armor and in the benefits of wearing armor and the limitations of its protection.**

Discomfort is probably the main reason why some officers who own armor do not always wear it. Wearers (and, especially, nonwearers) commonly describe their armor as "hot," "heavy," "stiff," "chafing," and the like. Complaints about chafing,

12 Soft body armor has a good record of protecting wearer against guns and ammunition more powerful than those it was advertised or certi.tied to protect against; nevertheless, in some eases rifle bullets and other high-energy bullets have penetrated armor not designed to stop it.

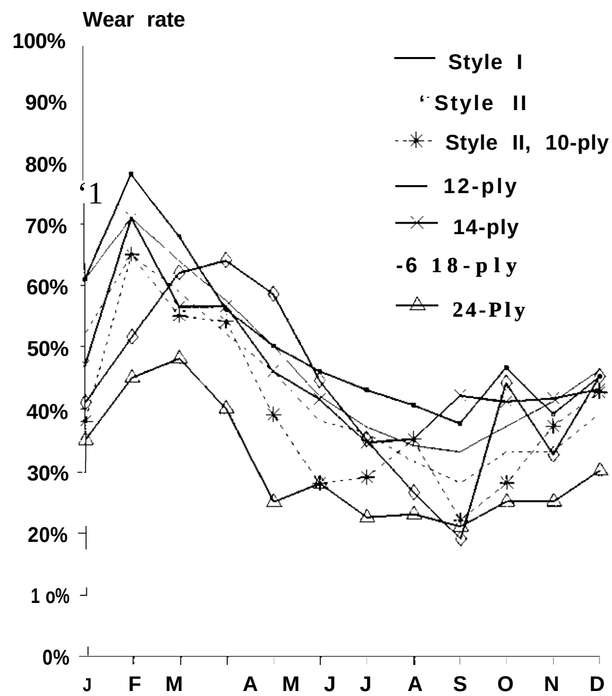
13 Many officers have been shot, and several killed, when off duty, in some cases while "moonlighting" as a private security guard.

Figure 5—Wear Rate Versus Temperature-Humidity Index (THI)



SOURCE: Aerospace Corp., 1977.

Figure 6-Wear Rate Versus Month



SOURCE: Aerospace Corp., 1977.

and to some degree about stiffness and the impression of great weight, may be the result of a bad fit, or of strapping the armor on too tightly. Ensuring good fit can encourage wearing of armor.

Officers' complaints that armor makes them feel hot, however, cannot be attributed to improper fit. Not only is armor material a good thermal insulator, it also blocks the evaporation needed for the body's normal perspirative cooling. A large, year-long survey conducted by the Aerospace Corporation for the NILECJ found that the strongest influence on wear rate (of those considered) was the Temperature-Humidity Index (THI).[14] Reported wear rates were higher at times and locations with lower values of the THI (See figure 5.), and higher in the winter months than in the summer. (See figure 6.) [7]

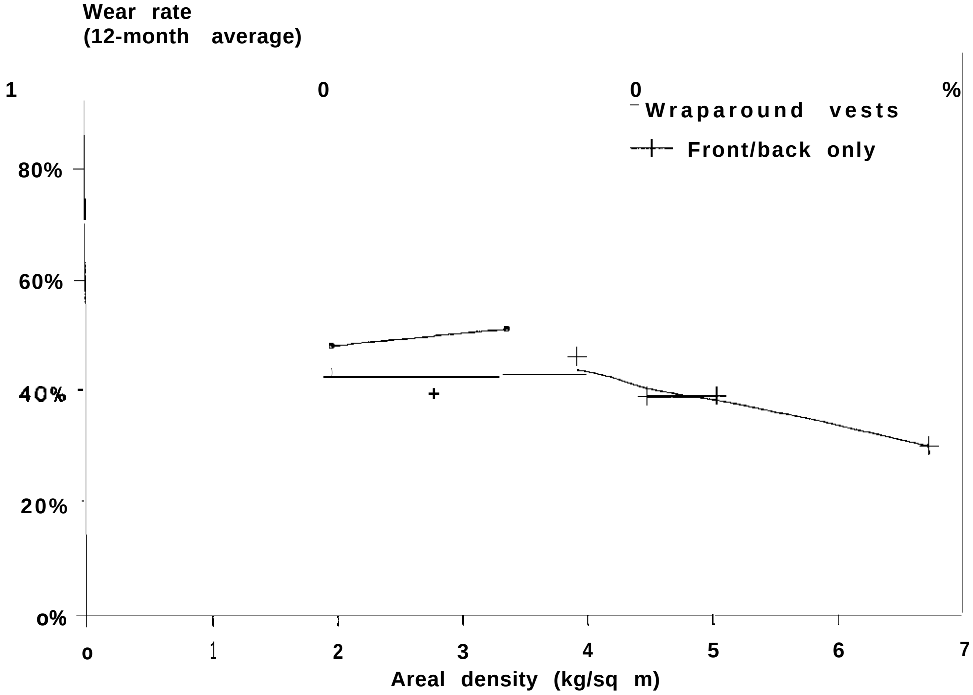
Some officers find they can lessen this blocking effect of the vest by wearing a special undergarment having vertical ribs designed to hold the vest away from the body and allow circulation of air under the vest.

Complaints about the weight of the vest are of particular concern, because weight—unlike chafing or heat retention—is directly related to the ballistic resistance of the vest. Stopping heavier, faster, harder bullets makes the vest heavier, as does protecting a greater fraction of the body. Thus, insofar as weight lessens comfort, there exists a true comfort-v. -protection tradeoff. However, an analysis of the Aerospace Corporation's survey data indicates that wear rate does not decrease markedly with increasing coverage or armor weight until the weight of armor material per unit area exceeds about 4.5 kilograms per square meter, which is typical of models certified to have type II-A ballistic resistance (see figure 7).[15] Lighter armor with less ballistic resistance was not worn more, but heavier armor with more ballistic resistance was worn slightly less.

14 The U.S. Weather Bureau defined the Temperature-Humidity Index by the formula $THI = 15 + 0.4 \times (T + T_W)$, where T = dry-bulb temperature @9, and T_W = wet-bulb temperature (?F).

15 Officers Participating in the survey had agreed to wear the armor; other things being equal, officers not obliged or ordered to wear their armor might be less likely to wear it than other officers, and their wear rate might show greater sensitivity to weight per unit area, although this is speculative.

Figure 7—Wear Rate Versus Areal Density of Armor



SOURCE: Office of Technology Assessment, 1992, based on data from Aerospace Corp., 1977.

Departments that are contemplating purchasing heavier armor should consider that the greater protection it could provide may be offset by a lower probability that it will be worn. Details will depend on region, season, type of duty, and individual physiology. This is less of an issue for tactical armor that can be tolerated for limited periods of high risk, even though uncomfortably heavy.

Goals of Testing and Certification

Purchasers and wearers of armor want to know whether a model of armor *will protect* them against a specified threat. Unfortunately, testing can only estimate the probability that the armor will stop a specified bullet and prevent the impact from injuring them. The estimate could be wrong, because identical tests of identical samples of armor may yield different results, and because the validity of the test (the correlation of its results with performance in service-see box G) is uncertain. Experiments designed to gauge the validity of a test can measure the statistical confidence (see box H) with which one can conclude that armor that passes the test would limit probability of injury to whatever level maybe required. However, the assessment of the validity **of existing or proposed test procedures cannot be objective or conclusive unless NIJ specifies the maximum acceptable risks of specific types of injuries or incapacitation by penetrating and nonpenetrating bullets, and the statistical confidence with which the validity of the test must be demonstrated.**

A test of ballistic resistance would be called ‘‘valid’ if armor that passes it is adequately safe in service. Hence, one cannot decide whether a test is valid unless “adequately safe” has been defined. Moreover, one cannot decide whether a testis valid unless “adequately safe’ has been defined *probabilistically—i.e.*, by specifying the maximum acceptable probabilities of specific types of injuries or incapacitation under specific conditions.

These maximum acceptable probabilities must be greater than O percent; no armor can be expected to protect a wearer with certainty, desirable though that may be. Even if, hypothetically, it could, that could not be shown “scientifically.” If, however, a nonzero maximum acceptable probability of each type of injury to be avoided were specified, then analyzing medical and ballistic data from shootings of persons wearing armor (primarily assaults on police officers) and subjecting the victims’ armor to

Box G—Stringency, Validity, and Reproducibility

In this report, a test of ballistic resistance, such as that specified by NIJ Standard 0101.03, is called *"stringent"* if a sample of armor has a high probability of failing it. Of course, the probability varies from sample to sample, so the term has only relative (not absolute) meaning.[1] Nevertheless, no matter what the probability is, certain changes in the test can increase it; others can decrease it. For example, requiring the sample to withstand more shots while allowing no more penetrations would increase any sample's probability of failing the test, hence it would increase the stringency of the test-

Increasing the stringency of a test may not make it better. Whether it does depends in part on the validity of the test. In this report, a test of ballistic resistance is said to be ***"valid" if*** armor that passes it is adequately safe *in service. This* **term, too,** *is* relative--validity depends on the safety criterion to be met. In any case, if the results of a ballistic test are completely unrelated to the performance of armor in service, the test would be invalid.. Valid tests may be have different types and degrees of validity; to describe them precisely and distinguish them requires statistical terminology (e.g., correlation between test outcome and penetration in service).

Whether increasing the stringency of a test is judged to be an improvement also depends on the judge's stake on the outcome. If a mandatory test is invalid, making it more stringent would strengthen whatever restriction it imposes arbitrarily on the freedom of the producer to sell, and the freedom of the consumer to buy, any armor they please.

If a mandatory testis valid, making it more stringent would increase the degree or the certainty of the protection it provides a wearer, which would be good for the wearer, other things being equal. But, depending on how it is done, increasing the stringency of the test might also fail the only armor that some would-be purchasers consider affordable (this would decrease sales), or the only an-nor that some potential wearers find comfortable enough to wear routinely (this would decrease wearing and might decrease lives saved). Others might find armor passing the more stringent test less comfortable, even though they tolerate and wear it. Clearly, different stakeholders will weigh the advantages and disadvantages of increasing the stringency differently. If the test is voluntary rather than mandatory, the effects would be less stark but more complicated to assess.

A test's validity is distinct from its ***realism.*** A test that shot each sample of armor with one bullet, fired from a gun (and a cartridge) drawn at random from those confiscated by police would be more realistic than the NIJ-specified test. The result of one such test would not be a reliable indicator of how armor like the sample tested would protect a wearer in service, nor could the same result be expected to be obtained in another test of a similar sample of armor. Conversely, tests designed to predict protection reliably would use many shots by a more limited variety of bullets than assailants use and would test several samples of armor.

A major concern of producers and purchasers alike is the ***reproducibility*** of a test, which could be defined as the probability that successive tests of "identical" samples will yield the same results (if the testis a pass/fail test) or results within specified limits (if the result of the test is a score). However, it is impossible to determine the reproducibility of a test, according to either of these definitions, because one cannot measure either probability.

A more practical but more complicated approach is to define the reproducibility of a pass/fail test in terms of lower confidence limits (corresponding to various confidence levels) on the probability that a sample will pass a test, given that an identical sample passed an identical test. Similarly, the reproducibility of a test that results in a score may be defined in terms of confidence limits on the probability of obtaining a score within specified limits, given that an identical sample attained a score within the same limits.

Actually, no two samples will ever be identical, nor will a test be conducted in ***exactly the same*** manner each time. Even if identical samples were tested in exactly the same way, the results could differ because of fundamental physical reasons. This makes it difficult, if not impossible, to scientifically test whether an observed variation in test results should be attributed to a variation of test procedure or, alternatively, to a variation of armor samples. In some cases, subsequent investigation has found a variation of either test procedure or armor samples that *might* have influenced the test results, but this does not prove that the variation was the sole cause of the differing results.

1 Furthermore, the probability that a particular sample will fail a test cannot be determined even after testing—it can only be estimated.

SOURCE: Office of Technology Assessment, 1992.

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Box H—Statistical Confidence

The idea of "probability" is clear to most of us: we understand the statement that "vest X has a 91 percent probability of stopping bullet Y going Z feet per second." Yet many statements about these probabilities are couched in terms of "statistical confidence," as in "90 percent confidence that vest X has at least a 91 percent probability of stopping bullet Y going Z feet per second." This sounds like an extra layer of waffling. Why is it needed?

It is needed because we can never test enough vests to be sure that the stopping probability is exactly 91 percent. After 100 shots and 9 penetrations, 91 percent would be a best guess (a "maximum-likelihood estimate": the probability that would have made the test results more likely than any other probability would). However, the true value could be 90 percent or 92 percent. Even after 1,000 shots with 90 penetrations, we can't be sure that we haven't been a little lucky or a little unlucky in our shooting.

For this reason, we need to express probabilities in terms of a level of confidence (such as 90 percent) that the true value lies in some range, called a confidence interval, that depends on the test results. For example, 100 shots with 9 penetrations gives 90 percent confidence that the stopping probability is at least 86 percent and 99 percent confidence that it at least 82 percent. This means if the stopping probability were no greater than 86 percent, there would have been a 90 percent probability of getting more penetrations than we did (9), and if the stopping probability were no greater than 82 percent, there would have been a 99 percent probability of getting more penetrations.

Conducting more tests narrows the range of probabilities (the confidence interval) that corresponds to some confidence level. For example, a total of 1,000 shots with 90 penetrations (the same fraction) gives 90 percent confidence that the stopping probability is at least 90 percent and 99 percent confidence that it is at least 89 percent.

SOURCE: Office of Technology Assessment, 1992.

the ballistic test in question, using bullets of the type with which it was shot (this is called a "reenactment"—of the test to which the armor might have been subjected before being used) would allow the validity to be decided "scientiilcally"—i.e., with an appropriate level of *statistical confidence, if the* test is accepted as valid,[16] or with an appropriate level of *statistical signficance, if the* test is rejected as invalid.[17]

What levels of statistical confidence and statistical significance are appropriate? The former must be less than 100 percent and the latter greater than O percent, otherwise an infinite number of reenactments would have to be performed. Aside from this, the choice is entirely subjective—a matter of acceptable risk. To avoid future controversy over such matters, NIJ should specify the levels of statistical confidence and statistical significance it deems appropriate for deciding validity.

It may, however, take months or years to collect enough data to decide the validity of a test with the confidence or significance required. Increasing the confidence or decreasing the significance required increases the number of reenactments required to decide validity.

Once validity is decided, the issue of appropriate stringency will be clarified:

- Invalidity is rejected with the statistical significance required by NIJ, the test should be changed.
- If validity is accepted with much more statistical confidence than the minimum required by NLJ, then it could also be concluded, with the minimum confidence required by NIJ, that to pass the test, armor must provide greater safety than required by NH-equivalently, that some adequately safe armor would fail, which would be unfair to its manufacturer. This would also argue for changing the test. However, no matter what the test, there is always some chance that adequately safe armor will fail. To preempt debate on this issue, NIJ should specify a maximum acceptable probability that safe armor

16 Here "statistical confidence'' refers to the probability that the test would have been rejected as invalid erroneously, if the probability of an injury to be avoided were as great as the maximum acceptable probability of njury, which in this context is called the upper confidence limit on the probability of injury.

17 "Statistic significance'' refers to the maximum probability that the test has been rejected as invalid erroneously, i.e., the probability that the test would have been judged invalid if the probability of an injury to be avoided were as great as the maximum acceptable probability of injury.

will fail-a maximum acceptable producer's risk, in the parlance of quality control.

- If validity is accepted with little more statistical confidence than the minimum required by NIJ, it cannot be argued that the ***testis*** (much) more stringent than necessary to meet the *safety goals.* To charge excessive stringency would be to charge that NIJ requires greater safety for wearers than the critic deems appropriate. It should be recognized that this is an essentially political issue, not a scientific one.

In 1976, NILECJ specified the maximum acceptable risk of death or serious injury by nonpenetrating bullets,[18] but did not specify the statistical confidence with which acceptable risk must be demonstrated. [106] The safety goals, which were proposed in a 1973 Army study for NILECJ, [104] have been phrased differently in different reports by those associated with NILECJ'S Lightweight Soft Body Armor Program. [74, 106, 145] This has caused some confusion about the precise meaning of the goals; clarification will be necessary in order to test the validity of the standard scientifically.

Moreover, NILECJ did not specify any maximum acceptable risk of penetration; it said only that armor "should prevent penetration by the bullet into the chest, abdomen, or back. ' If this means that no risk of penetration is acceptable, no test could determine whether armor satisfies this criterion: no matter how many tests resulted in no penetration, there would be no guarantee that the next shot would be stopped. A realistic goal would specify some nonzero maximum acceptable risk, and some statistical confidence with which it must be demonstrated.

Much of the current controversy over armor standards and testing arose and persists because the certification procedure does not quantify the risks, and the uncertainties in the risks, to manufacturers, purchasers, and wearers.

A risk for the manufacturer is that samples of a model will be tested and certified, and that samples produced later will be retested and fail. This has happened a few times. In some cases, no visible difference between the retest sample and the sample tested for certification was found.

Concerning one such case, TAPIC wrote, "It is apparent that when a marginal vest is submitted for multiple tests, it is to be expected that some will pass and some will fail. " [32] OTA concurs, but notes that marginal design or variations in production are not the only possible causes of variation in test results. Part of the variance of test results might be caused by subtle variations in test procedure.[19]

Although experiments can be designed to estimate the effect of deliberately controlled variations in samples or test procedure on the variance of test results, OTA knows of no way to attribute fractions of the unexplained variance of test results to (1) variations in samples, (2) variations in test procedure, and (3) irreducible randomness. Probably all contribute in some unknown proportion.

Apart from the problem of assigning blame for variation in test results to various hypothesized causes, there are fundamental limits to the amount of information that the passing of a certification test—any certification test--can provide about the probability that identical samples would pass an identical retest. Statisticians describe the limits in terms of the statistical confidence with which one can conclude that the probability of passing a retest is greater than some number called a lower confidence limit. "Statistical confidence" refers to the probability that the test would have been failed if the probability of passing it, or an identical retest, were as low as the lower confidence limit. The greater the lower confidence limit, the lower the statistical confidence with which one can draw such a conclusion.[20]

[18] Bullets stopped by armor often bruise or lacerate the skin behind the armor. Usually such injuries are minor; they do not incapacitate the victim (they often go unnoticed!) and require no surgery. However, a fast or heavy projectile stopped by light armor may bruise or rupture vital organs; this is called blunt trauma if unaccompanied by severe skin laceration. However, a bullet may even push armor into the skin, producing not only laceration but what surgeons call a penetrating wound, even though the armor is not penetrated.

[19] An inestimable—possibly very small-part is caused by the irreducible, quantum-mechanical randomness of physical phenomena.

[20] If the probability of passing a certification test or an identical retest were 1/2, the probability that the certification test would be failed would be 1/2. Thus *certification provides only 50 percent statistical confidence that the probability of similar samples passing a retest is at least 1/2.* It provides only 40 percent confidence that similar samples will pass a retest with a probability of at least 60 percent, 30 percent confidence that similar samples will pass a retest with a probability of at least 70 percent, etc.—no matter how much care is taken to make the samples of armor and test procedure uniform. Certification likewise provides only 50 percent confidence that similar samples will pass both of two retests with a probability of at least 1/4, or three of three retests with a probability of at least 1/8, etc.

Details of the test, such as whether armor is repositioned between shots, may affect the probability with which samples will pass a test, and if they are known to differ from test to test in a systematic way, such tests would not be ''identical.''[21] Steps can be taken to eliminate some possible sources of systematic test-to-test differences (see below), but it is doubtful all possible sources could be eliminated, and it is certain they could not be proven to be eliminated. Even if they *were* eliminated, one test could provide only limited statistical confidence (see fn. 21) in the corresponding confidence limits. This is not widely recognized; NIJ's criteria for certification and recertification should recognize such uncertainties explicitly and should advise manufacturers, purchasers, and wearers.[22]

It is not essential that the ballistic resistance of armor be tested under rare, extreme environmental conditions, provided customers understand the limitations of the testing. It would be reasonable for NIJ to specify optional tests for ballistic resistance under such conditions and to certify compliance of armor passing such tests at an approved testing laboratory. Such tests would increase the cost and stringency of tests while providing diminishing returns in terms of risk reduction, because shootings of officers under such conditions are rare.

It would be reasonable to *require* ballistic testing only under those conditions that research shows affect ballistic resistance substantially and occur at least 10 percent of the time when armor is worn. Allowing ballistic testing under less common conditions to be optional would permit (but not require) consumers to accept the risk that the actual ballistic resistance of armor could be less than the certified ballistic resistance up to 10 percent of the time. This does not mean the armor would be penetrated, or the wearer killed, by 10 percent of all bullets that hit armor; that would be the worst possible case. Even so, the risk, although unknown, could be significant, and NIJ might be unwilling to allow consumers who would accept it to buy armor certified by NIJ to provide a level of ballistic resistance only 90 percent of the time.

Nevertheless, there are arguments for accommodating such consumers:

- Designing armor to have rated ballistic resistance under some rare conditions may make it uncomfortable and decrease the probability it will be worn under all conditions.
- The validity of a test of ballistic resistance under a rare condition may not be demonstrable with reasonable confidence (at least, for several years) because few or no cases suitable for reenactment may occur.
- The costs of the extra testing required, which would be passed on to consumers, would be avoided.
- Consumers could (and should) be told of the conditions for which the rated ballistic resistance is certified, and of the most commonly occurring conditions known or believed to be detrimental and for which ballistic resistance is ***not*** certified. Consumers, thus informed, could decide to accept the risk.
- Optional standard tests for ballistic resistance under the more common rare conditions (e.g., wetting) should be specified for the benefit of purchasers who demand it and are willing to pay the passed-on share of the cost of the extra testing.
- There are precedents for accepting comparable or greater risks in return for economy, comfort, and other benefits. For example, in 1976 NILECJ stated the following goal for lightweight body armor: ''Any blunt trauma effects requiring surgical repair should have a mortality risk of 10% or less.''[23] [106] As another example, police officers rarely wear (and few possess) helmets providing ballistic protection, even though more than half of the officers killed wearing armor were killed by head wounds.[24]

21 The calculations above assume the probability of passing a test or retest remains constant, although unknown. However, a systematic change in test conditions, such as might be caused by a corrupt tester bribed to influence the outcome of retests, could cause the probability of passing retests to differ from the probability of passing the original test.

22 Options described below can limit t. any value desired the probability with which samples of a model that are actually typical would be judged erroneously, on the basis of retests, to be so atypical as to be unacceptable. Such options require several initial tests to characterize armor deemed typical and acceptable and would be more efficient (requiring less testing) if the test is one that results in a score rather than a pass or failure.

23 See also next Finding, and app. D (esp. box D-1) in vol. 2 of this Report.

24 From 1980 through 1990, of 170 U.S. law enforcement officers killed wearing armor, 104 (61 percent) were killed by head wounds. [140]

The 10 percent occurrence criterion discussed here for illustration is arbitrary. It would also be reasonable to require ballistic testing only under those conditions that research shows affect ballistic resistance substantially and occur at least, for example, 5 percent of the time. Deciding where to draw the line is a policy choice for NIJ, but requiring testing under conditions that occur no more than 1 percent of the time would be unnecessarily costly and the marginal benefit might not be measurable.

Two extreme conditions that have been the subject of recent controversy are exposure of armor to blistering heat and the heavy wetting of armor as a result of immersion, sweating, or rain. Although these conditions apparently are rare, lesser wetting of armor by sweat or rain is common. However, no one knows how frequently untreated fabric armor is wetted enough to degrade its ballistic resistance to some unacceptable level.

Test Procedures

This section describes OTA'S findings regarding controversial aspects of the test procedure specified by NIJ Standard 0101.03:

- the BFS test (for protection against injury by a stopped bullet),
- the number of shots required per panel,
- what non-penetration in testing says about risk of penetration in an assault,
- the test fixture on which armor is shot, and
- the prohibition on patting down bulges in the armor caused by previous shots in the test sequence.

Validity is at issue in all cases; the correspondence of test results to risk in service is uncertain. In some cases, the controversy is compounded by the lack of a clear specification of maximum acceptable risk, as noted above.

The impact of a bullet stopped by armor can kill or injure the wearer. Bruising and minor laceration is to be expected, but some test of the ability of armor to protect its wearer from critical injury is needed. The NIJ test, which is based on **the depth of the crater made in clay behind the armor when it is hit, serves this purpose. Of the armors that have stopped bullets in assaults, those that would have passed the NIJ test (for protection from a stopped bullet of the type it stopped in an assault impacting at the same speed as in the assault) limited the chance of death or life-threatening injury to about 1 in 300,** which is much smaller than the maximum risk acceptable to NILECJ in 1976: 1 in 10.

Armor fails the NIJ test if the depth of the crater (called the backface signature, or BFS) made in the clay behind the armor exceeds 44 mm. The 44 mm limit was based in part on NILECJ-sponsored experiments in which animals wearing one type of armor were shot with one type of bullet at a specified nominal velocity.[25,26] No Werner of NIJ-certified armor has suffered a type of injury that this test was designed to prevent, even though it was not intended to prevent such injuries with certainty. However, critics in the armor industry contend that soft armor designed to protect wearers from high-energy handgun bullets (type III-A) could be made lighter, more flexible, and more comfortable if the BFS limit were increased or if a resilient backing material were used, and they hypothesize that this could be done without exceeding the NILECJ-specified maximum acceptable risk.

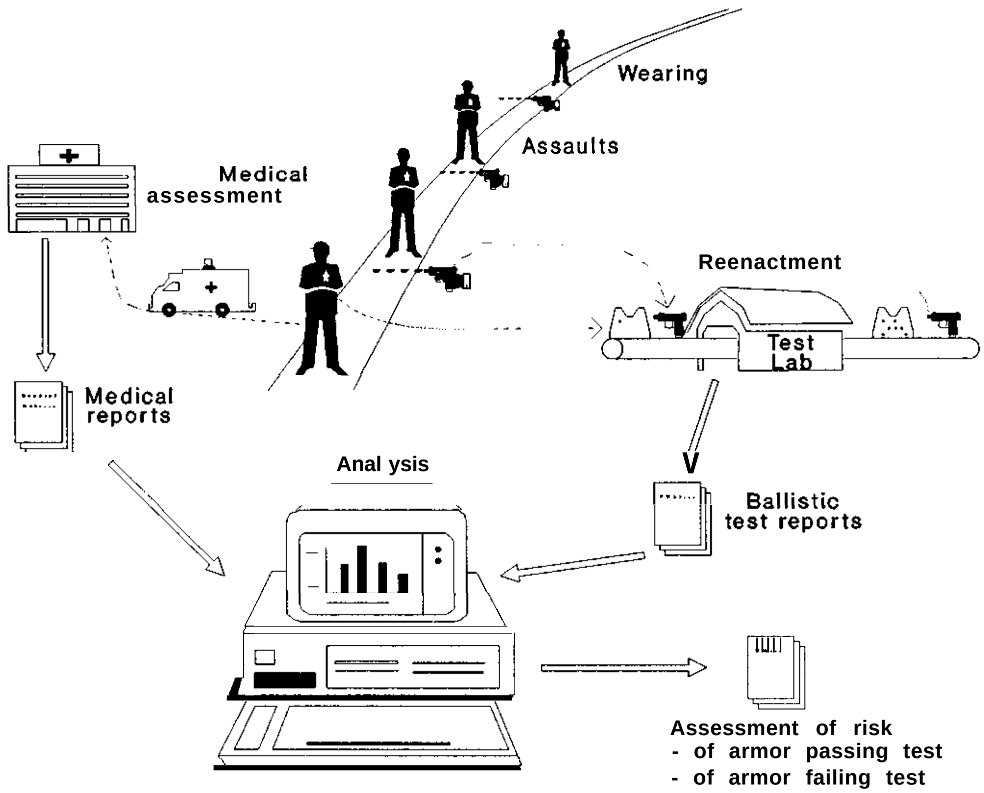
Now that hundreds of officers have been shot on their armor and a few thereby injured, it is possible to compare injuries sustained (or lack thereof) to the backface signatures produced in clay behind armor of the type worn, using weapons and cartridges of the types used by their assailants. Such measurements are called reenactments; they are reenactments not of the assault, but of a ballistic test the armor might have been subjected to (see figure 8).

Reenactments are a uniquely valuable, ethical tool for investigating the safety guaranteed by the existing NIJ test and for assessing alternative tests. In particular, they could provide the data required to estimate whether the 44-mm BFS limit is more stringent than required to meet the 1976 NILECJ

25 The research indicated 44 mm was an appropriate, if not conservative, BFS limit for .38-Special lead round-nose bullets impacting at about 8(X) feet per second (a type I threat) on 7-ply Kevlar armor. NILECJ Standard 0101.01 extrapolated the limit to all armors at all ballistic-resistance levels, assuming the BFS limit that would limit the risk from a high-energy bullet stopped by any armor to 10 percent would be no greater, and might be smaller, than the BFS limit for .38-Special bullets on 7-ply Kevlar armor [Lester Shubin, pers. comm., 13 Nov. 1991]. This was a reasonable conjecture at the time.

26 The NILECJ also funded Army experiments in which armored goats were shot with .357 Magnum and 9-mm bullets, as was armor on clay backing, but the research was not completed or published.

Figure 8—"Reenactment" of a Ballistic Test That Armor Shot in an Assault Could Have Been Subjected To



SOURCE: Office of Technology Assessment, 1992.

safety goals or any other goal NIJ might consider. DuPont had an independent laboratory perform several such reenactments in October 1991. OTA's analysis (appendix D) of the results (and the fact that only 2 to 4 of the roughly 600 shots stopped by armor caused serious injury) is the basis for the finding above.

OTA's analysis shed little light on the discrimination of the test—i.e., on whether the risk to wearers of armor that would have failed the test was substantially greater than the risk to wearers of armor that would have passed the test (see figure 9). To assess the discrimination of the test more accurately, more reenactments would have to be performed.

Although ND's 44-mm BFS limit has been a topic of considerable controversy, it has not been a major cause of certification-test failures: as of October 31, 1991, less than 3 percent of the models of armor submitted for an NIJ certification test failed solely because of excessive backface signature.[27]

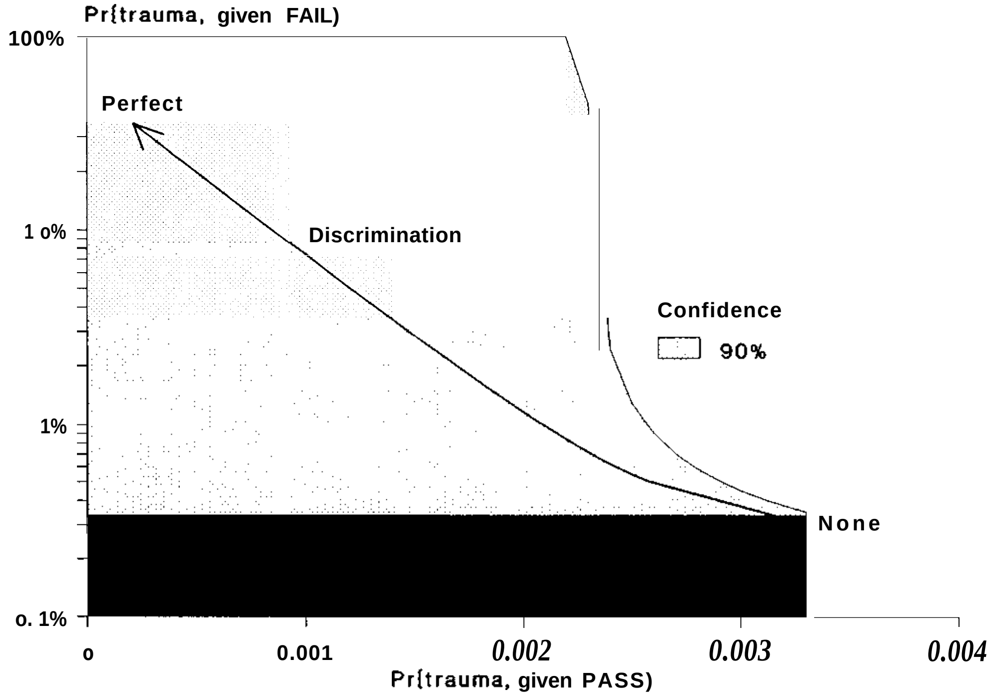
The relationship between the probability of armor penetration on human wearers and the probability of armor penetration in a NIJ test is not known.

The probability that a panel of armor will stop a bullet may vary from one location on the panel to another. It may depend on the number of shots that have previously hit the same panel. It may also depend on whether the panel is wet. The fact that each of four panels has stopped six fair shots in a test only provides information about the geometric mean (a kind of average[28]) of stopping probabilities averaged over all shot locations and wet/dry conditions. In particular, it allows one to calculate the statistical confidence with which the geometric-mean stopping probability exceeds any confidence

27 This figure is for samples submitted to TAPIC and tested for certification of model compliance with NIJ Standard 0101.03.

28 The geometric mean of 24 probabilities is calculated by multiplying them and raising the result (the product) to the Power 1/24.

Figure 9—Discrimination of the NIJ Test for Protection From the Impact of Stopped Bullets



Reenactment data provide 90-percent conf idence that the risk of trauma to wearers of armor that would have passed the test (Pr{trauma, given PASS}) and the risk of trauma to wearers of armor that would have failed the test (Pr{trauma, given FAIL}) are in the shaded region shown. If they were at the upper left-hand corner of the region, the test would have perfect discrimination; if they were at the lower right-hand corner of the region, the test would have no discrimination. This result indicates that Pr{trauma, given PASS} is less than about 0.0025 unless the test has little discrimination.

Whatever the value of Pr{trauma, given FAIL}, if Pr{trauma, given PASS} were at the right-hand boundary of the region, there would have been a 90-percent probability that the reenactment results would have led to a greater maximum-likelihood estimate of Pr{trauma, given PASS} than the one actually obtained (0). This is what "90-percent confidence" means.

SOURCE: Office of Technology Assessment, 1992.

limit of interest.[29 30] This information is important for characterizing the reproducibility of test results, but it says nothing about the mean stopping probability on human wearers averaged over shot locations and conditions of assaults.[31] That is an issue of validity.

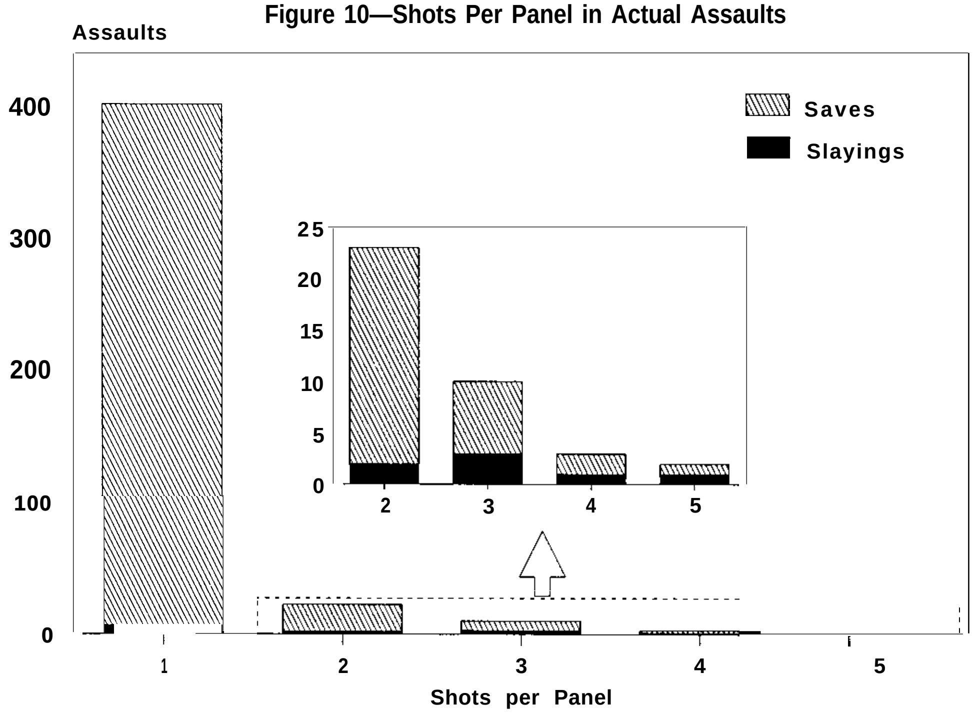
The DuPont-sponsored reenactments showed that, in an assault, armor may stop a projectile of a type it is unlikely to stop in a test. Physical reasoning, and ballistic tests sponsored by Allied-Signal, suggest that part of the reason for this apparent discrepancy is that most types of projectiles are more likely to penetrate typical armor if they hit it broadside, as in most shots of the NIJ test, than if they impact at an angle, as often happens in assaults. The backing material used in the test may also make a difference. Performance and analysis of the additional reenactments would yield more information about the

29 For example, if the geometric-mean stopping probability were 90 percent, there would be a 92 percent chance that one or more penetrations would have occurred; thus the geometric-mean stopping probability (on clay) is at least 90 percent with 92percent confidence. By the same reasoning, it is at least 95 percent with 71 percent confidence, at least 99 percent with 21 percent confidence, and at least 99.9 percent with 2 percent confidence.

30 The level-IV test requires only one shot per panel—only two shots in all—and therefore provides very little statistical confidence that the stopping probability is as high as most would want. It provides 75 percent confidence that the stopping probability is at least 50 percent, but only 51 percent confidence that it is at least 90 percent, and only 2 percent confidence that it is at least 99 percent.

31 Army tests indicated that 40-grain, .22-caliber long-rifle high-velocity bullets have even odds of penetrating 7-ply Kevlar armor test panels at about 1,o79 ft/s on one sample of clay,1,088 ft/s on another sample of clay,1,115 ft/s on goat chest, and 1,096 ft/s on goat abdomen.[114] There are related data, not yet analyzed, for 9-mm, .357 Magnum, and .45-caliber threats [Russell N. Prather, pers. comm., Jan. 10, 1992], but none for human wearers.

Figure 10—Shots Per Panel in Actual Assaults



SOURCE: DuPont, 1991, based on DuPont and FBI records.

correlation of armor penetration on clay with armor penetration on human wearers. This information could be used to determine the number of shots a certification test must have to infer whether the armor limits the probability of penetration to whatever level may be required by policy, with the confidence required. (The probabilities of penetration on clay and in service need not be equal for the test to be valid, but the relationship between them must be known, at least statistically.)

Neither the six-shot per panel NIJ .03 test nor the five-shot per panel NIJ .02 or PPAA tests reflect expected assault conditions: in a typical shooting in which an officer's armor is hit, only one panel is hit, and by only one shot. The .02, .03, and PPAA tests for soft armor specify five or six shots per panel partly for conservatism (i.e., to simulate a worse-than-expected multi-shot assault) and partly for economy (i.e., they require additional shots on a panel in lieu of shooting them at separate panels, which would increase the cost of testing).

In over ***90*** percent of 440 felonious shootings of armor wearers, only one shot hit the armor. In only two cases—less than 0.5 percent-did five shots hit a panel. In no case did six shots hit a panel (see figure 10). [16][32] To simulate these assaults in terms of shots per panel, a realistic 48-shot test[33] would require shooting 23 complete armors,[34] about six times as many as the .03 standard requires: two to six (nominally four) complete armors.

The realism of NIJ-compliant testing would be improved if the NIJ standard were revised to allow testing of a whole armor garment on a test fixture, such as a mannequin, to which the armor could be affixed by the strapping or fasteners a wearer would use. Such a revision would also create an incentive for technological innovation. For example, stitching elastic strapping directly to the

[32] These data are based on FBI records of 14 slayings of armored officers from 1980 through 1989 ("fatal wounds occurred outside vest area") and 426 saves from 1973 through 1989 recorded by the IACP/DuPont Kevlar Survivors' Club (S.M.). In addition, there were five saves with an unspecified number of bullets stopped by one panel and one or two bullets stopped by the opposite panel. Furthermore, an unknown number of armor-wearing officers were non-fatally hit on unarmored areas of the body.

[33] Reducing the total number of shots would reduce the amount of information the test would provide about the ballistic resistance of the armor.

[34] A realistic 48-shot test would require two shots on each of two panels and one shot on each of 44 panels, requiring 46 panels and hence 23 complete armors to be shot.

ballistic panels might reduce ply separation of some armor in an assault as well as in testing, which would improve the reproducibility of test results.

NIJ has considered alternatives to the fixture specified in the .03 standard and has had the National Institute of Standards and Technology's Office of Law-Enforcement Standards (NIST/OLES) conduct tests of three alternative fixtures: (1) the clay block specified by NIJ Std. -0l0l.03 in a square frame, (2) a mannequin as specified by PPAA STD-1989-05, [113] and (3) an experimental curvilinear test fixture (called "the curv") consisting of a rectangular frame holding a clay block but with semicylindrical sides facilitating the attachment of a complete armor by means of its own strapping and fasteners (see photo).

NIJ found the curv to be superior to the .03 block, partly on the grounds that ballistic tests of identical armor showed greater consistency on the curv than on the block. [149] Other advantages of the curve, relative to the clay block, are: (1) the greater realism of testing whole armor attached by its own strapping and fasteners; and (2) the practical necessity of doing so to test an integral armor garment (e.g., one made with a single, -wrap-around, non-removable ballistic element). A mannequin of the type specified by PPAA would also have these advantages.[35]

As noted above, NIJ recently directed H.P. White Laboratory, Inc., to use the curvilinear test fixture for tests of model compliance withNIJ Standard O101.03. However, the standard itself was not changed, so other testers may continue to use the clay block specified by the standard.

Requiring adjustment ("patting down") of armor between shots would control shot-to-shot **and test-to-test variability of test conditions. For armor susceptible to ply separation, this would decrease the stringency of the test but would more realistically simulate typical assaults, in which one panel of armor is hit by only one bullet. It might simulate assaults with multiple hits per panel less realistically.**

Ballistic tests of identica1[36] armor panels indicate that ply separation contributes to the penetration probability of some types of armor, especially unquilted fabric armor. Patting the armor down between successive shots (to reduce or eliminate ply separation, push the armor against the backing, and smooth the backing) reduced the penetration probability and hence also the stringency of the test and the variance in penetrations (a measure of shot-to-shot differences) .37

Some critics of the NIJ standard argue that ply separation ("bunching" or "balling") does not occur in actual assaults and that it should therefore be corrected in certification tests by patting the armor down between shots. Most of the evidence adduced consists of statements by survivors of shootings, who claim their armor did not bunch up, or that they recall that their armor did not bunch up, or that they do not recall their armor bunching up.[38]

Some critics theorize that the dynamic, elastic human torso oscillates after being shot and pats the armor down *from the inside.* Clearly the chest or abdomen, after being indented by a stopped bullet, does return to its pre-impact position (unless the stopped bullet fractures a bone or the armor penetrates the skin). However, biomechanical research

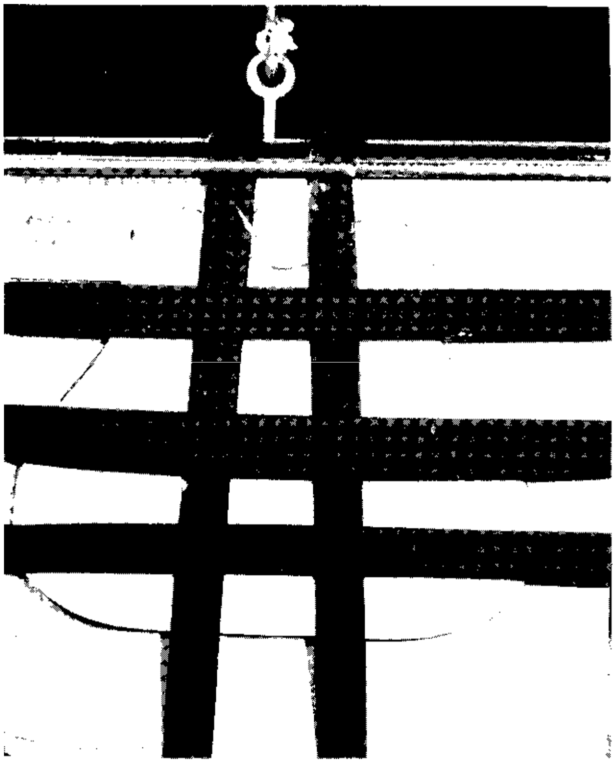
35 NIJ also found the curv to be superior to the PPAA mannequin. In these tests, the face of the clay in the mannequin's box was planed to facilitate accurate measurement of the backface signature. When armor was mounted on the clay, it arched over the clay in the box, and was not "in intimate contact' with the clay as required by both NIJ Std. 0101.03 and PPAA STD-1989-05. NIST noted this may have contributed to ply separation, hence to penetration and variance in results. OTA believes this is not an appropriate comparison, nor is it consistent with provisions in NIJ Std. 0101.03 for testing of type III or IV ballistic resistance or female models of armor; those provisions, like PPAA STD-1989-05, require clay to be mounded behind the armor panel to assure the panel is in intimate contact with the clay. BFS measurement would be most accurate if the first shot impacts a flat area of the clay, but this need not include the whole face of the clay block.

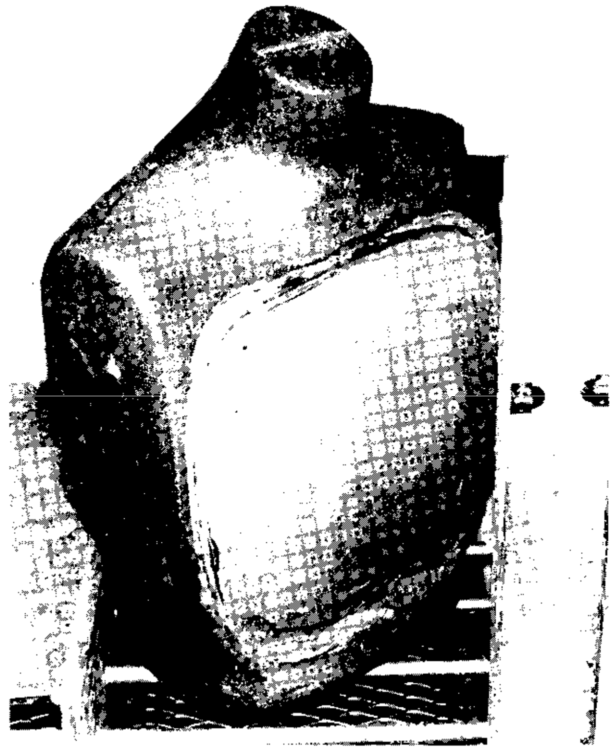
36 That is, armor panels made to be as nearly identical as the manufacturing and quality-assurances processes permitted.

37 Here we assume the probability of penetration on *any* shot is less than one-half, as it is with high confidence in almost all certification tests. Otherwise, reducing the penetration probability would increase the variance.

38 The reliability of such assertions is doubtful. We do not doubt the integrity and conviction of those who make such statements, but considerable psychological research shows that recollection of inconsequential circumstances surrounding a threatening or traumatic event is frequently mistaken. For example, "research. . . with Air Force flight-crew members confirms that even highly-trained people become poor observers under stress. The actual threat that brought on the stress response, having been highly significant at the time, can be remembered; but memory for other details such as clothing and colors is not as clear . . . ." [30]

Mounting Fixtures for Ballistic Tests of Body Armor





Top left: Clay block specified by NIJ Std. 0101.03 in rectangular frame.

SOURCE: El. du Pent de Neymours & Co., Inc., 1992.

Top right: Mannequin with clay-filled cavity specified by PPAA STD-1989-05.

SOURCE: Office of Technology Assessment, 1991.

Bottom right: Experimental curvilinear frame tested at HPWLI by NIST/OLES for NIJ.

SOURCE: Office of Technology Assessment, 1991.

suggests that the sternum (breast bone) would do so slowly and would not rebound outward.[39]

On balance, this is too little information to decide conclusively how common and marked ply separation is in multi-shot assaults. Worse, we **know of no ethical means of finding out, so the controversy may continue indefinitely. Even so, it would be reasonable to revise the standard to require patting, with the rationale that the revised test would more realistically simulate the most common type of assault—assaults with one impact per panel—but would fire several such shots at each panel in the interest of economy. Whether to trade off conservatism about rare assaults for greater realism in simulating typical assaults is a policy choice for NIJ. There is no technical reason not to.**

Assuring Quality

NIJ's certification procedure certifies adequacy of design. It does not assure product quality, nor does it prevent fraud in the marketplace. It attests that a few samples of each NIJ-certified model did pass a test specified by the NIJ standard and implies other samples *could also* pass the test if constructed in the same manner as the original samples. But ***certification provides no assurance*** *that they are so constructed.*

Clearly, assuring product quality would require selecting samples of production armor periodically and testing the samples. It would also require using statistical methods to estimate the probability that the units not tested would pass the test; if it is too low, certification would be denied, suspended, or revoked.

OTA has considered two approaches in detail: (1) lot sampling and acceptance testing and (2) statistical process control. These are described below, under Options for the Department of Justice, and in greater detail in appendix E.

UNRESOLVED ISSUES

More research will be needed to assess the discrimination of NIJ's test for protection from the impact of a stopped bullet, to estimate the BFS limit appropriate for whatever safety goal NIJ may specify, or to identify a test with better discrimination between reliable and unreliable armor. Clearly (see Findings) armor that would have passed the test has limited the chance of injury by a stopped bullet of the type, and at the velocity, used in the test, to less than 1 in 300-but so has armor that would have failed the test. Possibly the test discriminates poorly—i.e., the risk of trauma to wearers of armor that would have failed the test may differ little from the risk of trauma to wearers of armor that would have passed the test; if so, the allegation of some manufacturers that the test has little discrimination would be borne out. To decide whether this is so would require performance and analysis of additional reenactments.

Data from additional reenactments could shed light on other issues related to protection from stopped bullets. They could be used to estimate (1) how risk (in aggregate and by threat) would vary if the BFS limit were varied and (2) the BFS limit appropriate for whatever safety goal NIJ may specify. If additional reenactments are conducted, it would be convenient to measure, at the same time, quantities other than crater depth (e.g., crater diameter); this could allow a test with better discrimination to be identified (see next option).

Tests based on crater depth and other measurements (e.g., crater diameter or deformation velocity or pressure) should predict acceptable protection from stopped bullets more reliably than does the current test, which is based on crater depth alone. More measurements would provide more information; further research could compare the cost-effectiveness of tests based on different sets of measurements. For example, the Army developed (for NILECJ) a method to predict the lethality of a stopped bullet based on the bullet's mass and velocity, the armor's weight per unit area, the wearer's weight and body-wall thickness, and the diameter of the crater made by the armor in clay backing. With some adjustment (and, ideally, validation by reenactments), the method could be used to gauge protection from a stopped bullet for armor certification. Very likely, other models based on the same or additional measurements would be even

[39] A biomechanical model described in app. C predicts that the sternum (breast bone) would not rebound outward beyond its pre-impact distance from the spine, and it would take about 50 milliseconds-the interval between successive shotsofaMAC-11 submachine gun-for the compression caused by a stopped bullet to subside to 37 percent of the maximum compression. The abdomen would probably take longer.

more reliable, but research would be needed to confirm this.[40]

Untreated fabric armor without waterproof covers is apparently rarely wetted in service (by perspiration, precipitation, or immersion) to the extent that its ballistic resistance is clearly degraded; however, the frequency **of such wetting is not known. Hence, if the NIJ standard were amended to make wet-testing optional (as critics propose), we do not know how much greater risk an officer would face wearing dry-certified armor than wearing wet-certified armor. Nor do we know how much more frequently the officer would wear dry-certified armor than wet-certified armor. We suspect the answers to both questions depend on climate, type of duty, and individual physiology, and we expect individuals or departments could answer them as well as OTA or NIJ could. They** could measure wetting of their armor by weighing it. However, they would require assistance-training, instructional materials, or worksheets—to estimate the probabilities of wearing and wetting and to understand the uncertainties in the estimates.

The status qu0--certification of armor only if samples pass the test after being sprayed—guards against the possibility that armor may become dangerously wetted. However, critics of the NIJ standard question the need for the wet testing, arguing that “waterproofing causes more trouble than it’s worth, because it gives the wearer a rubber-sheet effect, making the body armor too uncomfortable to wear.”[41] [120]

Defenders of the standard point to the profuse sweating that wearing any vest can cause in hot weather, and to the possibility of immersion, as exemplified by an assault in which an officer[42] was held underwater by an assailant who attempted to drown him and then shot him twice in the back, on his armor, with his own revolver.[43] Even in this case, it is not known whether the armor was wet, or how wet it was, where the bullets hit.

If such wetting occurred as much as 5 percent or 10 percent of the time, it would very likely have caused penetrations, in assaults, of uncertified, non-wet-tested armor, which in fact has saved hundreds of police officers and not once been penetrated by a bullet it was advertised to stop.[44]

No one denies that *fabric* armor not treated to repel water loses some ballistic resistance as its water content increases.[45] However, it fully recovers its resistance after drying. Soaking such armor may degrade ballistic resistance dramatically; spraying it with salt water to simulate sweating had a negligible effect in one series of tests; [105, 106, 8] we do not know how spraying as spectified by NIJ Standard 0101.03 affects the ballistic resistance of various armors.

Tests conducted for NIJ by MST’s Law Enforcement Standards Laboratory in 1990 showed the V_{50} (the velocity at which bullets have a 50 percent chance of penetrating) of Kevlar[R] panels decreased with increasing water content as shown in figure 11. [62]

To use this information (or similar information about other bullets or armor) to assess the risk of unacceptable degradation of ballistic resistance, one would have to know the statistics of moisture pickup by armor worn by the wearer or wearers of interest.

In an experiment conducted at the FBI Academy, untreated Kevlar[R] armor worn by an instructor performing prolonged strenuous activity (on a‘ ‘hot, humid day” [62]) absorbed and retained perspira-

40 See appendix E for further details.

41 Fabric armor that passes a test dry can be made to pass it wet by treating the ballistic fabric or the fiber from which it is woven, by enclosing the ballistic element in a waterproof cover, or by using more layers of untreated fabric. Some treatments may make the armor more costly or less comfortable.

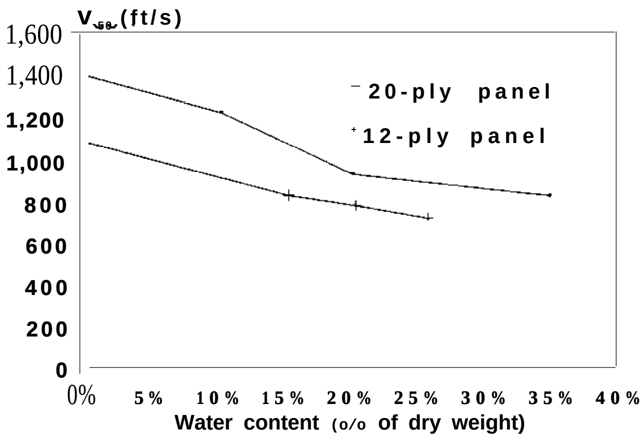
42 Ohio State Trooper Cardinal.

43 The me I 8-ply Kevlar back panel of the officer’s Point Blank armor (which had a Type IIA front panel) stopped both shots, even though both impacted close to the edge of the ballistic panel, where armor is not tested for ballistic resistance. The shots made a hole extending from 13/d inch to 33/A inch from the edge of the carrier garment’s pocket for the ballistic panel. The ammunition was CCI 125-gr JSP .38 Spl +P.

44 Uncertified armor not designed to provide rated performance when soaked is credited with more “saves” per vest sold than comparable certified (wet-tested) armor is. Mr. Clinton E. Davis, Executive Vice-President, Second Chance Body Armor, Inc., wrote, “Our records show over the last eighteen (18) years that 10 percent of the non-waterproofed vests in the field have accounted for 40 percent of the saves. This means that a non-waterproof concealable vest is six (6) times more likely to be worn. ” [46] OTA is not persuaded of the last point, because non-wet-tested armor has been on the market and in service about six years longer than wet-tested armor has, allowing more opportunities for more saves. However, it is plausible that a non-waterproof concealable vest *is* more likely to be worn.

45 Soaking does not cause armor made from nonwoven Spectra Shield[R] composite material to lose ballistic resistance.

Figure 1 l—Effect of Wetness on Ballistic Resistance of Kevlar[R] Armor



124-gr 9mm FMJ

SOURCE: Office of Technology Assessment, 1992, based on data from NIST/LESL, 1990.

tion equalling 22 percent of its weight, which could **cause a** considerable loss of ballistic resistance (see fig. 11). [8] If ballistic resistance is to be certified even for such conditions of heavy and prolonged perspiration, spraying or immersing the armor before ballistic testing is necessary. However, some—perhaps most-duties will not cause enough perspiration **to** significantly degrade the ballistic resistance of untreated fabric armor,[46] and moisture pickup may depend on fabric[47] and individual physiology.

By wearing and weighing untreated fabric armor, an individual could estimate how often it becomes dangerously wet. By alternately wearing waterproof armor, he or she could decide whether it is less comfortable; if not, there would be no reason to wear the untreated armor. However, we doubt many officers would conduct such an experiment at their own expense, and what they learn would not help others.

NIJ could solicit volunteers for a similar nationwide experiment and provide them with armor. For the results to be useful in various jurisdictions, NIJ would have to determine how wetting and wear rate (or comfort) depend on various factors, such as the ambient (outdoor) Temperature-Humidity Index and whether the wearer spends most of the time in a climate-controlled environment. One of the problems of such **a** study would be **reliance on volunteers**; those who do not volunteer may be the **ones** most sensitive to comfort-the ones hypothetically most benefited by untreated armor.

Departments that order and enforce the wearing of armor would be in **a** position **to** randomly select subjects and order **them** to participate. However, the department would face an ethical dilemma: could it justify ordering an officer to stop wearing wet-tested armor and instead wear untreated armor for the duration of the experiment, knowing there is a possibility it might be wetted enough to be degraded and then shot in that condition? The risk appears low, but such an experiment must be performed to measure it. It may happen that the risk is more than offset by the increase in wear rate. A decision to do so would be analogous to a common one: deciding to issue type II or II-A armor rather than type III-A armor, because of comfort, economy, or expected wear rate; the type III-A armor promises better protection.

In summary, there is an apparently small but unquantified risk that non-wet-tested armor might be wetted enough to be degraded and then shot. However, wet-tested armor might be worn less often than non-wet-tested armor. There is no compelling evidence that requiring wet-testing costs more lives than it saves, but neither is there a compelling rationale for continuing to require armor to be tested wet, as the current NIJ standard does. Revising the NIJ standard to allow armor to be tested wet or dry would allow purchasers to choose armor that they believe offers the most protection, considering wear rate as well as ballistic resistance, and considering local and personal factors, such as climate and type of duty. They might err, and more research would be needed to give them better guidance.

OPTIONS FOR THE DEPARTMENT OF JUSTICE

Some have questioned the need for **a** Federal role in the formulation of standards for body armor intended for use by State and local police **officers,** yet no serious contention has surrounded the assignment of that role-given that it should exist—to the

[46] The untreated armor worn by another subject in the FBI experiment [8] who spent his shift in a car picked up only 5 percent perspiration.

[47] When saturated, Spectra™ fabric holds less water than does saturated Kevlar™ fabric.

Department of Justice.[48] Within the Department of Justice, the role again finds a natural home: the National Institute of Justice, created in 1979 by the Justice System Improvement Act. NIJ's mission is ''to encourage research and development to improve the criminal justice system and to disseminate the results to Federal, State, and local agencies. ' [144] A major part of NIJ's effort to assist law-enforcement agencies with the acquisition of new technology is the issuance of voluntary standards for a variety of police equipment, including radios, weapons, automobile tires, and body armor. The Office of Law-Enforcement Standards (OLES) of the National Institute of Standards and Technology (NIST) assists NIJ in developing and revising standards, including the standard for ballistic resistance of body armor.

Although no significant body of opinion holds that the body armor question lies outside of NIJ's mandate or purview, many have expressed the feeling that NIJ has become unduly wedded to the existing standard. They feel that long-standing conflict over the body-armor issue among persons whose strong personalities and knowledgeable minds are driven by the earnest desire to save the lives of as many police officers as possible has solidified positions, especially those in NIJ, to a degree beyond that justifiable on purely scientific or technical grounds. This perception constitutes a public relations problem for NIJ.

It is clear the standard should be revised—eventually. It could be revised now to reduce the latitude in test procedures permitted by the standard. This would limit lab-to-lab and test-to-test variations in test conditions, which might be partly responsible for variations in test results. Minor variation in test conditions occurs in normal testing; its influence may be minor or insignificant. However, it is possible a tester may have some incentive to conduct a test "by the book" but in a manner intended to maximize (or, depending on the incentive, to minimize) the probability that the armor will pass the test. Minor revisions in the standard could limit the latitude of such inadvertent or operator-controlled variation in test conditions. The section ***Revise NIJ Standard 0101.03*** (below) describes several such revisions; they include specifications of bullets and backing material, reducing the range of allowed backing-material temperature, measuring backing-material temperature and consistency more frequently, and patting down armor between test shots. Revising the standard to specify a number of specific procedures already used at H.P. White Laboratory, Inc. would further limit possible lab-to-lab variations in test conditions. (Recall that any individual with two guns, modelling clay, a thermometer, a steel ball, and a ballistic chronograph can test samples of armor and certify the model's compliance with the NIJ standard on the labels of other units of the model.)

Moreover, as discussed above in **Findings, the validity** of the current test has not been demonstrated-nor can it be until acceptable risks are specified. This lack of demonstrated validity does not require revising the current standard. But if NIJ wishes to assure purchasers and wearers of the protection afforded by a ***unit*** of certified armor, it must (1) specify its safety goals so the validity of the current test or a proposed revision maybe tested; (2) test the validity of the test specified by the standard; ***(3)*** revise the standard, if required for validity, and **(4)** implement a quality-assurance program to ensure that certifiled armor offered for sale is as safe as the samples that passed the (valid) test of ballistic resistance. All the items on this list are discussed in the next four subsections: ***Specify Acceptable Risks, Revise NIJ Standard 0101.03, Assure Quality,*** and ***Sponsor Research.***

Specify Acceptable Risks

Specifying acceptable risks would allow the validity of the current test to be decided scientifically and would give NIJ a yardstick for assessing options for revising its test and its certification process. NIJ should specify the types and degrees of injuries and incapacitation by penetrating and non-penetrating bullets that the armor is to prevent and the maximum acceptable risks of such injuries and incapacitation (as well as the statistical confidence with which acceptable risk must be demonstrated). Illustrative options for doing so are listed below.

Safety goals should be weighed carefully, bearing in mind they benefit only those who *wear* certified armor. **Making the goals extremely stringent could decrease the number of such officers and increase the ranks of those who wear uncertified**

[48] See, however, **Other Policy Options**, below, regarding the jurisdictions of the Federal Trade Commission (FTC) and the Occupational Safety and Health Administration (OSHA).

armor or none. Requiring very high confidence that the test limits the probability of whatever type of injury is to be avoided to a very small number will make the cost of testing the validity of the test very high and will increase the cost of compliance testing and of producing certified armor. It may also require armor to be thick, stiff, and heavy in order to have a reasonable chance of passing the test. Such armor would probably be worn less, which could cost lives, on balance.

A statement of goals could be of the following generic form:

Certified armor should:

(1) Stop each shot, up to ***n*** per panel, with probability p_s or greater.

(2) Leave wearer ambulatory with no injury rated higher than ***ion*** the Abbreviated Injury Scale[49] [88] after each stopped shot, with probability p_a or greater.

Reenactments or other tests should:

(3) Demonstrate that armor meeting the certification criteria will accomplish goal (1) with at least Cl-percent confidence and goal (2) with at least C_2-percent confidence.

Customizing this statement requires choosing values of n, p_s, i, p_a, and C. The parameters *n* and p_s specify the required protection from penetration *in an assault* by whatever projectile may be specified: *n* is the number of shots the ballistic element (e.g., panel) is to withstand, and p_s is the minimum reliability with which *each* of them is to be stopped. Thus if a panel is to stop each of six shots ($n = 6$) with **97** percent reliability ($p_s = 0.97$), then it should stop *all six* shots with **83** percent reliability **($0.97^6 = 0.83$).**

A ballistic test used or proposed for certification of armor's ballistic resistance may require more or fewer than *n* shots per panel. Whether it provides the protection required by this safety criterion (viz., from *n* shots per panel) is a question of validity that can only be settled (ethically) by reenactments designed to test the validity of the test. If the safety criterion requires the armor to withstand more impacts of the specified bullet per panel than have ever hit a panel of armor in service, the validity of the test cannot be tested scientifically. If there are enough assaults of the appropriate type to perform reenactments and test validity, the conclusion may depend on the required reliability, and will depend on the confidence **(C_1)** with which validity is **to** be demonstrated. Requiring **extreme** reliability and confidence will ensure that any ballistic test will fail a test of validity. If NIJ wants a demonstrably valid test, it must not require that a panel withstand more than a few shots, nor that it withstand them with 100 percent reliability, nor that this be demonstrated with 100 percent confidence.

The parameters *i* and p_a specify the required protection from stopped projectiles *in an assault. The* parameter ***i*** designates the maximum tolerable severity of injury, on the following scale:

Abbreviated Injury Scale

6: fatal
5: critical-survival uncertain
4: severe, life-threatening-survival probable
3: severe, not life-threatening
O-2: not severe

Protection from incapacitation may also be specified-for example: "Leave wearer ambulatory. . . ." It is tempting to specify "Leave wearer ambulatory and able to hit a man-sized target in a vital area with at least one round from service weapon (etc.)," but it would be difficult or impossible to demonstrate scientifically that a ballistic test meets such a requirement. The ability to walk away—a useful capability in itself-is more easily tested and can be considered a "proxy" (a plausible substitute) for other desirable capabilities, the validity of which may be impossible to confirm.

The parameter, is, again, a kind of reliability—the reliability of protection from severe injury or incapacitation by a stopped bullet. More of it is better, but the higher the value specified, the lower the confidence with which reenactments can confirm validity. Requiring extreme reliability (p_a) and confidence (C_2) will ensure that any ballistic test will fail a test of validity.

The illustrative generic safety goals are necessarily technical in order to make it possible to test their validity scientifically. Even if realistic parameter values are chosen, it may take years before a test of

49 We expect NIJ would want armor to prevent injuries with AIS ratings of 6 (fatal), 5 (critical: survival uncertain), and 4 (severe, life-threatening: survival probable) with a high probability. NIJ could allow injuries rated 3 (severe, not life-threatening) or below on the AIS, on the grounds that requiring armor to prevent them may have a negative, but as yetunquantified, effect on wear rate.

Table 3—Choices for Safety Goals

Option	n	p_s	i	p_a	c_1	C_2	Rationale
1	6	0.97	3'	0.99	50	99	Goals defined implicitly by NIJ Standard 0101 .03@ [c]
2	6	0.95	3	0.95	95	95	NIST hypothesized p_s,[d] to balance risks, p_a, C_1/1 OO, and C_2/100 assumed equal.[e]
3	6	0.90	3	0.95	95	95	Less than half of penetrating torso wounds are fatal.[f]

Notes:

[a] "Severe, not life-threatening." The next higher injury rating, 4, which is to be avoided, means "severe, life-threatening; surviva! probable."

[b] NIJ Standard 0101.03 requires, implicitly, only 50-percent statistical confidence that the geometric-mean stopping probability *on day* is at least 97 percent, for soft armor. The calculation, based on the test of 24 fair shots per caliber with no penetrations, is: $C_1/100 = 1 - p_s^{24}$, thus 0.50= 1-0.971524. The standard is also consistent with ($C_1 = 90$, $p_s = 0.92$), ($C_1 = 95$, p_s - 0.71), and other combinations. However, the p_s in the safety goal refers to the stopping probability on wearers, in service. This is tacitly assumed to be comparable to the stopping probability on clay, but additional research would be needed to test the hypothesis.

[c] The implicitly required safety from stopped bullets is greater than required by the NILECJ, as discussed above in Findings.

[d] NIST hypothesized p_s = 0.95 (on clay) as an illustrative boundary between bad and marginai armor (see appendix E).

[e] To balance risks and compensate forthe fact that the explicitly accepted risk of penetration has been increased from O percent to 5 percent, the acceptable risk of life-threatening injury from a stopped bullet has been decreased from 10 percent (the NILECJ goal) to 5 percent.

[f] The ailowed risk (1- p_s) of penetration is twice the allowed risk (1- p_a) of iife-threatening injury by a stopped bullet, because fewer than half of penetrating torso wounds are fatal. This may balance risks more carefully than option 2.

SOURCE: Office of Technology Assessment, 1992.

the validity of **a** ballistic test with respect to the goals may be completed. They will have to be explained in terms familiar to police officers. The present question for NIJ is whether to specify safety goals explicitly and realistically enough so they can be used as a standard against which the validity of ballistic tests of armor can be assessed.

Table 3 shows three possible combinations of parameters for the generic **statement** of safety goals and provides a brief rationale for each option. All are realistic and, we believe, comparable in some ways to what NIJ Standard 0101.03 was intended to require. However, these options are more rigorous in that they specify confidence levels with which validity is to be demonstrated. It is harder to demonstrate that a ballistic test meets a safety goal requiring only 97 percent reliability in stopping each shot and **50** percent confidence that the reliability is that high than to demonstrate that the test meets a different safety goal requiring 100 percent reliability in stopping each shot but no specific confidence that the reliability is that high.

Revise NIJ Standard 0101.03

This section describes the most important options for revising NIJ Standard 0101.03. Appendix E discusses these (and others) in greater detail.

Whatever other changes are made, some of the latitude in test procedures permitted by the standard should be reduced to limit lab-to-lab and test-to-test variations in test conditions, which might be partly responsible for variations in test results. Since NIJ Standard 0101.03 was issued in 1987, the **H.P.** White Laboratory, Inc. (HPWLI), which currently is the only ballistic test laboratory authorized by NIJ to do testing for certification by NIJof compliance with the standard, has adopted particular ways of conducting the test in the interest of reproducibility. NIJ has also issued directives instructing the H.P. White Laboratory to perform parts of the test in particular ways that are not the only ways allowed by the standard. Other laboratories attempting to conduct a test in accordance with the standard+. g., for developmental testing of a new model—might conduct their testing in accordance with the standard but not exactly in accordance with the procedures H.P. White Laboratory would use for certification testing of the model.

The lab-to-lab variations in test conditions might cause lab-to-lab variations in test results. To preclude this, when NIJ does revise NIJ Standard 0101.03, the many de facto requirements that have been specified by letters, telephone calls, or established practice at H.P. White Laboratory should be incorporated explicitly into the revised standard. This would limit the ways in which test conditions could differ from laboratory to laboratory, and, at laboratories other than H.P. White, from test to test.

Revise the Backface Signature Limit

The backface signature limit specified by the standard could be revised based on the maximum risk of injury NIJ will accept and the statistical confidence it requires in the validity of the BFS test. The amount of each demanded is a policy choice for NIJ (see *Specify Acceptable Risks,* above). Of all possible limits that would satisfy the safety goals, NIJ could choose the one that maximizes discrimination—i.e., that minimizes the estimated probability of misclassification of acceptably safe armor as unacceptable or vice versa.[50]

The maximum allowable BFS might be calculable from existing reenactment results, depending on the safety goals. For example, if NIJ chooses to allow at most a 1 percent probability of life-threatening injury from a stopped bullet (even if survival is probable), then permitting any BFS but prohibiting penetration would accomplish this with better than 99 percent confidence, if armor designs and the firearms threat change no more than they did in the past two decades. Additional research would be necessary to determine BFS limits appropriate for some safety goals NIH might specify (e.g., if NIJ undertakes to protect wearers against injuries rated 3 or lower on the Abbreviated Injury Scale).

Require Patting Down of Armor Between Shots

The standard could be revised to require patting down of armor between shots. This would simulate typical assaults (those that cause only one impact per panel) more realistically than does the current test. However, it might simulate assaults causing multiple impacts per panel less realistically. It would limit inadvertent shot-to-shot and test-to-test variability of test conditions, and would limit opportunities for any operator (tester) to deliberately influence the probability of passing by aiming either at or between the "hills" caused by the bunching effects of previous shots. It would decrease the stringency of the test in that it would give armor of models susceptible to ply separation in testing an increased probability of passing.

Specify Standard Bullets

The bullets to be used in the test could be specified more precisely. The probability with which a commercially available bullet of specified mass and caliber will penetrate armor at a specified velocity depends on the bullet's construction and composition. [28] A bullet that deforms may be stopped by relatively few layers of armor; many more layers may be needed to stop sharp fragments of a hard or steel-jacketed bullet.

Specifying more precisely the bullets to be used in the test could increase reproducibility of test results. It would not simulate the diversity of the threat faced by police officers (neither does the current set of test bullets), but reenactments could assess the reliability with which armor tested with standard bullets stops bullets that hit wearers.

Specify Standard Backing Material

The backing material to be used could be specified. Specifying the backing material to be used for the test might improve its reproducibility. In practice, only one backing material, Roma Plastilina No. 1 modeling clay, is used by HPWLI for NIJ certification tests. However, NIJ Standard 0101.03 does not require it; a tester may use any material that passes the "drop test" specified to check the consistency of the backing material.

Some backing materials conditioned to pass the drop test yield different backface signatures at the much higher deformation velocities typical of a ballistic test conducted in accordance with NIJ Standard 0101.03.[51] Thus the drop test does not assure that backface signatures produced in different backing materials behind similar armors by similar bullets impacting at similar velocities will be the same. Some materials are known to yield different results; others, not yet tested by NIJ or NIST, could differ more dramatically. Specification of a backing material would eliminate this potential source of

50 Alternatively, NIJ could choose the one that minimizes its expected utility, [9] but this would involve assessing the value of a life saved in monetary or other terms to which the values of other possible benefits and losses may be compared. This has proven controversial in other fields, such as automotive safety engineering. [76]

51 For example, in tests conducted b, the British Police Scientific Development Branch, under otherwise similar conditions the average (viz., fitted) backface signatures produced in U.S.-made Plastilina and U.K.-made Plasticize were similar at impact velocities of 350 m/s but differed by about 4.4 mm for each 100 m/s above or below 350 m/s. [29] Cf. [28, 84].

variation in-or operator influence on—test conditions.[52]

Reduce Tolerances on Backing Material Properties

The allowable range of backing material temperature could be reduced, and the temperature or consistency of the backing material (or both) could he required to be measured at specified time intervals or stages of ballistic testing.

The consistency (flowability) of clays commonly used for backing has been shown to be very sensitive to clay temperature. Variation in the temperature of clay backing material could make the difference between passing and failing NIJ's test for protection from stopped bullets. In 1977, the Aerospace Corporation recommended that, for adequate reproducibility, backing material be maintained at 70° plus or minus 2°F.

NIJ Standard 0101.03 allows backing material to have a temperature between 15 and 30°C (59 and 86°F) during testing. It requires the consistency of the material to be tested three times by dropping a specified weight from a specified height and measuring the depth of the crater it makes. In practice (at the H.P. White Laboratory), all three drop tests are conducted before—not during or after-testing. Possibly the consistency may change during testing, e.g., as a result of bullet impacts or as the material's temperature approaches ambient temperature (which is required to be in a narrower range than the material's temperature). In tests observed by OTA, the backing material cooled during testing.[53] Possibly this happens in a uniform way at H.P. White, but it could vary from lab to lab. Moreover, the latitude permitted by the standard could be exploited to influence test results.

Reducing the allowable range of backing material temperature, and requiring temperature to be measured and consistency to be tested at specified time intervals or stages of ballistic testing would limit the latitude for deliberate or inadvertent variation of test conditions, even within the bounds allowed by the standard, or inadvertent transgression of the bounds. It may improve the reproducibility of backface signature measurements, especially of crater diameter, which could be used in assessing protection from blunt trauma. It might also improve reproducibility of penetration tests.

Certify Wet and Dry Ballistic Resistance Separately

The wet test could be mandatory or optional. Some purchasers or wearers may prefer armor with inadequate wet ballistic resistance because of cost or comfort. They may suspect the risk of its becoming dangerously wet is so low they would accept it. But to learn what the risk is, they would have to weigh their armor regularly to measure and record water retention and analyze the records to calculate frequency with which retention exceeds dangerous levels. In compensation, wear rate might be increased among those who find armor with inadequate wet ballistic resistance more affordable or comfortable but who also value NIJ's certification.

Subjecting armor only to the dry testing specified in the NIJ standard would reduce the stringency of the test, even for armor that performs as well wet as dry. If NIJ wished to compensate for this and maintain the stringency of the test, it could offer a choice of the current wet-dry test or a double-dry test with the same number of fair shots required.

To halve the cost of testing, one industry source has proposed testing and certifying dry ballistic resistance *or* wet ballistic resistance, but not requiring both tests. This is based on the premise that no conceivable type of armor has less ballistic resistance when dry than when wet. This is plausible, but even if true, armor would have a higher probability of passing a wet-only test than a wet-dry test with twice as many shots.

Rate the Ballistic Resistance of Each Certified Model With a Score

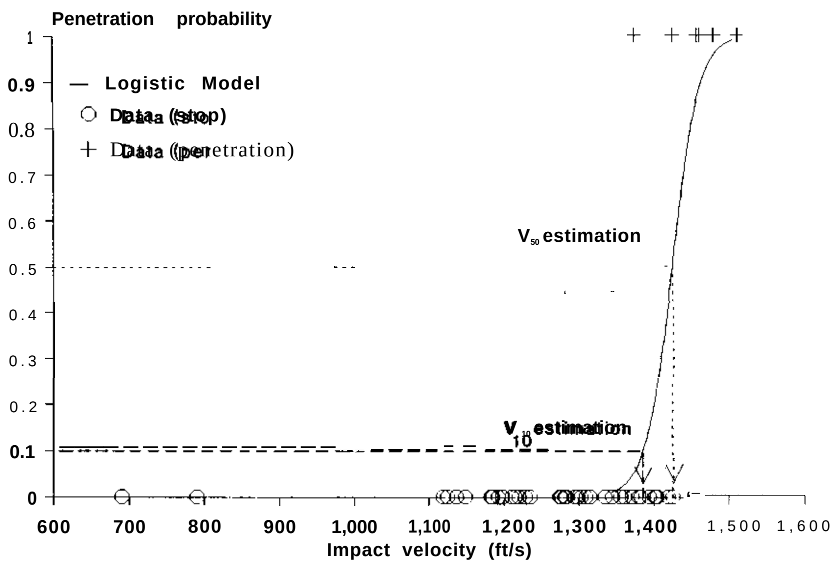
The standard could specify a way to rate the ballistic resistance of each certified model with a score, such as the V_{50} ballistic limit-the velocity at which test bullets have a 50 percent chance of penetrating.

The present certification test is a pass/fail test, although armor may be tested for resistance to any type of bullet at any velocity. Nevertheless, knowing

52 Although clay composition demonstrably affects the results of the deformation test (for protection from nonpenetrating bullets), it is not certain that it affects the results of the penetration test. More research would be needed to find out whether it does.

53 However, after the last shot at each panel, craters were filled with clay warmer than the rest of the face of the clay block.

Figure 12—Estimates of V_{50} and V_{10} Obtained by Logistic Regression



.357 Magnum at 30° incidence v. panel on clay, smoothed between shots.

SOURCE: Office of Technology Assessment, 1991.

only that a model has passed does not indicate the velocity at which the test bullets would be expected to penetrate it. Indeed, that velocity cannot be estimated unless the test requires some test bullets to impact at a velocity high enough to penetrate the armor samples.

A test developed by the Department of Defense [138] for estimating the V_{50} of (unbacked) armor could replace NIJ's current test of resistance to penetration.[54] A model could be certified to have a specified type or level of ballistic resistance if the V_{50} for each type of test bullet equals or exceeds a specified minimum value, and if samples also pass a test for protection from blunt trauma. But the model would be rated as well as certified, to let purchasers know the model exceeds minimum NIJ standards-and by how much.

An alternative score is the V_{10}, the velocity at which test bullets have a 10 percent chance of penetrating-i.e., at which armor stops a bullet with 90 percent reliability. It could be estimated by logistic regression [91] based on velocities and penetrations measured in a DoD-like test (see figure 12). For purchasers who demand 90 percent, rather than 50 percent, reliability in stopping, the V_{10} would be more appropriate for comparing to typical or conservative threat velocities than would the V_{50}. However, probability of penetration in service may differ from probability of penetration in the test.

A sample's V_{05} or V_{01} could likewise be estimated by logistic regression, and certification could be based on them. However, there would be more uncertainty in these estimates than in estimates of V_{10} or V_{50}; achieving comparable accuracy would require firing more shots than would be needed to estimate V_{10} or (esp.) V_{50}.

Use Anthropomorphic Test Fixture

The standard could be revised to allow or require testing of a whole armor garment on an anthropomorphic test fixture to which the armor could be affixed by the strapping or fasteners a wearer would use. This would improve the realism of the test and would be necessary to test integral armor-armor made from a single panel of ballistic material stitched so that it can not be spread flat on a clay block. The curvilinear frame developed and tested by NIST for NIJ would be a suitable fixture; so

54 The DOD test uses air as the backing material, but NIJ could specify that clay or some other backing material be used. Regardless of the material used, calibration of penetration probability in the test with penetration probability in assaults would be an issue.

would the mannequin specified by the PPAA. For either fixture-but especially for the mannequin-it would be prudent to require aim points to be at least 2 inches from the frame or clay box walls, to limit whatever effects their proximity may have on penetration probability or deformation.

The standard should continue to require that the armor be placed in intimate contact with the backing material. This may require mounding the backing material behind some parts of some armors. However, the standard could require the backing surface to be flat within a specified (perhaps threat-dependent) radius about the first aim point, to permit backface signature to be measured to the current standard of accuracy.

The standard could specify test fixtures of various sizes to accommodate armors of various sizes. NIJ Standard 0101.03 specifies that samples be sized for 46- to 48-inch chests, explaining that ‘the larger the size, the more likelihood that all ballistic testing will fit on just two complete armors.” However, it may be that smaller armor is less likely to pass the test, other things being equal—that is, size may be ballistically significant. We do not know whether it is, and we do not know that it is not, but qualitative physical arguments suggest that it might be.[55] Hence a more conservative provision would require separate certification, and hence testing, of each size, which might require fixtures of several different sizes. This would be costly—it would increase the nonrecurring cost to the test lab, which would have to stock several fixtures, and the recurring cost to manufacturers, who would have to conduct more testing.

A simpler, less costly, and even more conservative option would be to require the samples to be the smallest size in which the model is offered.

Certification of lots (rather than models) as described below would require the test lab to have fixtures of various sizes to accommodate samples of various sizes. However, it would not require each size of each model represented in a lot to be tested; two tests per lot would suffice in some cases.

Assure Quality

OTA found (see Findings above) “NJ’s certification procedure. . . does not assure product quality, nor does it prevent fraud in the marketplace. ’ This section describes briefly two options, either or both of which NIJ could implement if it wants to assure buyers and wearers that each *unit* of armor certified to comply with the current NIJ standard (or a successor) and offered for sale has been subjected to sampling for inspection and ballistic testing to confirm its adequacy or its similarity to samples previously found to be adequate.

Many variants of these illustrative options maybe invented; they would provide different types of guarantees-some statistical, others non-quantitative. They would assure product quality and provide assurance against some imaginable types of fraud in the marketplace. Preventing false or deceptive labeling or advertising is discussed below, under Other Policy Options.

Certify Lots

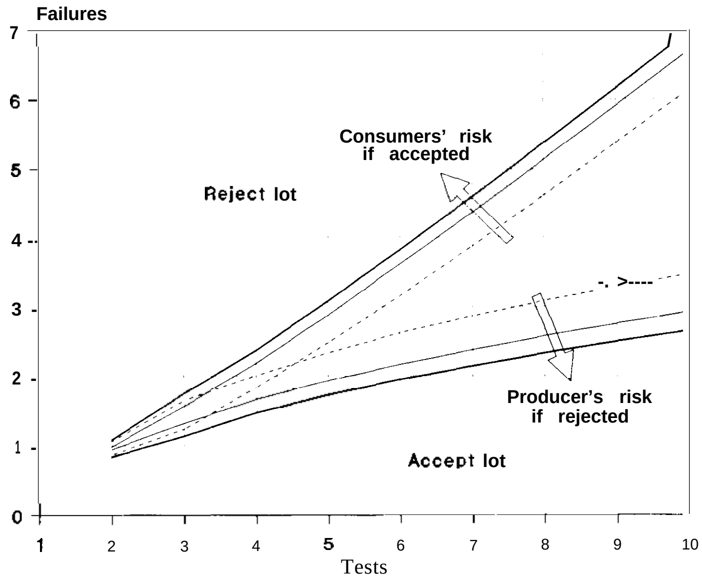
NIJ could certify lots, rather than models, of armor. This would certify acceptability of product quality, not just acceptability of model design. If intentional or inadvertent changes in manufacturing caused the ballistic resistance of units (nominally) of a certain model to degrade, this option would keep lots with unacceptably low ballistic resistance off the market, with a probability that can be made as high as desired by testing a sufficient number of samples per lot. Either the ballistic test specified in NIJ Standard 0101.03 or a different one could be used.

To exercise this option, NIJ would have to

1. Define a lot.
2. Specify a sampling plan--i.e., the number of samples from each lot to be tested, and criteria for acceptance and rejection based on test results.
3. Ensure the samples to be tested are selected randomly from each lot.

55 When armor stops a bullet, the armor is bent, stretched, and often cut or torn near the point of impact. A second shot may be more likely to Penetrate if it impacts in the damaged area than if it impacts eLsewhere. The standard’s requirement that each test shot impact at least 2 away inches from any point of prior impact is intended to prevent this influence. However, the radius of weakening might extend farther than 2 inches from a point of impact; the extent of weakening would depend on the bullet, its velocity, the armor, and the backing material.

Figure 13—Notional Control Chart for Sequential Lot-Acceptance Testing



SOURCE: Office of Technology Assessment, 1992.

Any of several sampling plans could be used.[56] A sequential procedure that OTA finds appropriate

- is based on a pass/fail ballistic test for individual units;57
- allows a lot to be inhomogeneous;[58]
- defines a unit as "bad" if it has a probability of passing less than a value p_b to be specified by NIJ;
- defines a unit as "good" if it has a probability of passing greater than a value p_G to be specified by NIJ;
- limits the probability of accepting a lot containing one or more "bad" units to the maximum consumers' risk acceptable to NIJ; and
- I.i.rNIJs the probability of rejecting a lot containing only ''good' units to the maximum producer's risk acceptable to NIJ.[59]

Samples would be selected randomly from the lot and tested. Testing could be allowed to continue until the fraction of tests failed is so great that the lot must be rejected to limit the consumers' risk or so small that the lot must be accepted to limit the producer's risk. To decide when a lot must be accepted or rejected, a "control chart, " such as the one shown in figure 13, could be used.[60]

Establish **a Voluntary Quality-Control Program**

NIJ could establish and supervise a voluntary quality control program analogous to the Listing or Classification programs of Underwriters Laboratories, Inc. (UL). UL **Classification** of a model of armor would be based partly on ballistic testing of samples and partly on inspection of the manufacturer's manufacturing and quality assurance processes **by NIJ** or a contractor.

56 However, some Widely used procedures may be inappropriate-for example, those that assume a' 'defective' unit of armor will always be correctly identified as such by inspection or testing.

57 The .03 Special-Type test could be used, if armor were only tested wet, so that only one unit of armor would be required for each test.

58 The testing of samples would indicate whether all units have acceptable—not necessarily equal—ballistic resistance. In some other approaches to quality control, it is important that a lot be homogeneous, i.e., thall units in the lot be alike, at least insofar as can be determined before testing.

59 The last two objectives are accomplished by 1-sided Kolmogorov statistical tests [45] based on the results of the ballistic tests.

60 See app. E of vol. 2 for details.

The cost of UL or UL-like procedures for assuring body armor quality would depend on how samples are selected, the standard to which they are tested, and the confidence (if any) with which the tests are to assure that the samples are identical to the original test articles or, in any case, provide the ballistic resistance required.

A simple option would be Classification of a model of armor as compliant with NIJ Standard 0101.03 or a similar standard. This would require iNIJial testing of samples in accordance with the standard. Continuation of Classification would be contingent on audits of the manufacturer's production and quality control processes and on selection, inspection, and ballistic testing of production samples to gauge their similarity to the iNIJial samples. UL estimates iNIJial testing of a model could be performed for about $3,000, with each additional model (from the same manufacturer) tested at the same time costing about $1,500. Ongoing Follow-Up Service would require four annual visits and cost little more than about $700 to $1,000 per year, if the manufacturer's quality control program is in good order. [112]

However, this option would not provide quantitative estimates of the maximum risk of UL-Classified armor. Moreover, some manufacturers might hesitate to participate in it because they would perceive unannounced factory inspections as being intolerably intrusive.

Sponsor Research

Some OTA findings noted gaps in the knowledge needed for rational standard-setting that could be filled by additional research. For example, one noted that "the relationship between the probability of armor penetration on human wearers and the probability of armor penetration in an NIJ test is not known." OTA also noted two Unresolved Issues that might be resolved by further research:

> "More research will be needed to assess the discrimination of NIJ's test for protection from the impact of a stopped bullet, to estimate the BFS limit appropriate for whatever safety goal NIJ may specify, or to identify a test with better discrimination between reliable and unreliable armor. "

> "Tests based on crater depth and other measurements . . . should predict acceptable protection from stopped bullets more reliably than does the current test, which is based on crater depth alone. . . . Further research could compare the cost-effectiveness of tests based on different sets of measurements. "

The following options for research are aimed at reducing or eliminating these gaps in knowledge. NIJ could propose, through the budget process, a specific program of research for funding by Congress (see Legislative Options, below).

Investigate Resilient Backing Material

NIJ could investigate the use of resilient backing material for penetration testing. Use of resilient backing material, such as foam rubber or silicone rubber, for penetration testing might make ply separation and penetration probability during testing comparable to that in an actual assault. However, there is little objective information about how much ply separation occurs in any shootings of armored humans, especially in assaults, and we doubt there is an ethical way of learning much more about it. The correlation of penetration in assaults with penetration on resilient backing in tests could be estimated by conducting reenactments of assaults (see below).

The current BFS measurement on clay backing or some other test (see below) could be used to estimate risk of injury from stopped bullets.

Sponsor Additional Reenactments of Assaults

NIJ could sponsor additional reenactments of assaults for any or all of several purposes, for example:

- To estimate the risk, and confidence limits on the risk, of injury by stopped bullets, as a function of backface signature depth. Additional reenactments would allow the dependence of risk of injury (especially minor injury) on backface signature to be inferred with greater statistical confidence than has been possible based on the limited number of reenactments performed to date.
- To estimate confidence limits on the risk of injury by stopped bullets, as a function of backface signature diameter or measurements other than backface signature. These might predict serious injury more reliably than does backface signature diameter. The Army developed a procedure for predicting risk of lethality as a function of backface signature diameter, but it is based on animal data and should be validated, if possible, using human data; we expect adjustment will be required.

- To infer a relationship between the probability that armor will be penetrated on clay backing material in a test and the probability that similar armor will be penetrated in an actual assault.
- To infer relationships between the probabilities of armor penetration on backing materials other than clay and the probability that similar armor will be penetrated in an assault. Penetration in assaults may correlate better with penetration on a resilient backing material such as foam rubber or silicone rubber than on modeling clay.

Develop Parametric Models of Mortality and Morbidity From Stopped Bullets

NIJcould develop parametric models of mortality and morbidity from stopped bullets—mathematical formulae or graphs that predict the probabilities that a single nonpenetrating shot would kill or cause unacceptable trauma, based on parameters that describe the threat (bullet mass and velocity), the armor (areal density), ballistic test results (BFS), and the wearer (e.g., weight). The model could be fit to data from reenactments of shootings of armored humans, or, using a different procedure, to data from the experimental shooting of animals. Limits on BFS depth or diameter could be based on the model, the maximum acceptable risk specified by policy, and the parameters describing the threat, the armor, and the wearer.

An advantage of using such models as a basis for certification is that assessment of the protection new types of armor provide against various threats would not require additional biomedical tests (i.e., shooting large mammals, and killing some); it would only require additional ballistic tests: shooting the armor of interest with bullets of interest at velocities of interest, using a backing such as clay.

This would be more complicated and cumbersome than the current procedure. On the other hand, it would provide a rationale for certification of protection against trauma caused by bullets other than Type I bullets stopped by armor other than 7-ply Kevlar armor. It also would allow armor to be certified for use only by wearers large enough to face only an acceptable risk; smaller wearers are probably at greater risk than larger wearers in similar (but larger) armor.

Sponsor Research on Tests for Protection From Stopped Bullets

NIJ could sponsor research on the practicality and validity of tests for protection from stopped bullets based on measurements other than backface signatures. Some experts speculate that measurements of pressure in backing material behind armor during impacts of test bullets might predict serious blunt trauma more reliably than BFS depths do. There is a plausible argument-but as yet no proof—that backing pressure may be a better predictor of certain functional injuries of the heart (e.g., ventricular fibrillation or block) that can be caused by blunt impacts. In experimental animals, such injuries correlate with backing velocity times deformation (a “viscous criterion”), which can be reconstructed from measurements of backing acceleration during impact.

Research on such correlations and on measurement techniques has been conducted, and continues, at General Motors Research Laboratories and abroad, in England, France, and Germany (see app. E). However, more research is needed to correlate measurements of each type with various types of injuries to various vital organs. As with the BFS criterion, validation will ultimately require reenactments of assaults on humans.

Appendix E discusses other options for the Department of Justice.

OTHER POLICY OPTIONS

The Federal Trade Commission (FTC) and the Occupational Safety and Health Administration (OSHA) have jurisdiction in some matters related to body armor: the FTC has authority to prosecute cases of false or deceptive advertising or labeling,[61] such as the incorrect labeling of armor as an NIJ-cert~led model, and has done so. OSHA could protect the occupational safety of police officers by requiring them to wear approved armor under specified conditions, but has not done so.

Expand FTC Activities; Involve OSHA

***The Administration could direct** FTC or OSHA to expand activities within its jurisdiction related to body armor.* For example, if further complaints of false or deceptive advertising or labeling are alleged,

[61] See the Federal Trade Commission Act (38 Stat.717, as amended (15 U.S.C. 41-58)); the Clayton Act (38 Stat.730, as amended (15 U.S.C. 27)), and the Federal Trade Commission Improvements Act of 1980 (94 Stat. 374-397).

investigation and prosecution are within FTC's jurisdiction. NIJ must play a role because inspection of samples for conformance with those submitted for certification testing will require access to the submitted samples archived by NIJ's Technology Assessment Program Information Center (TAPIC).

If the Administration desired to mandate the wearing of approved armor on duty, OSHA has the authority to do So.[62] This would require collaboration by OSHA, which has experience in and infrastructure for regulation, and NIJ and NIST, which have expertise in the standardization and testing of body armor.

LEGISLATIVE OPTIONS

Fund NIJ-Sponsored Research

Congress could authorize and appropriate funding for NIJ-sponsored research on topics cited above in Options for the Department of Justice:

- Investigation of resilient backing for penetration testing.
- Reenactments of actual assaults, to test the validity of the current test for blunt-trauma protection or help design a new one.
- Measurement of backing pressure or acceleration in reenactments, and correlation with blunt trauma in assaults.
- Development of a logistic model that predicts the incidence and severity of trauma from stopped bullets, as a function of multiple measurements, to be used as a basis for armor certification; also
- Periodically updating such a model using data from reenactments.

Enact H.R. 322, the Police Protection Act of 1991

Congress could enact H.R. 322, the Police Protection Act of 1991, which would prohibit sale of armor not certified to comply with the current NIJ standard or any future revision thereof, and would authorize NIJ to enforce this ban. Thereafter Congress could fund the mandated program of NIJ regulation.

This would be a sweeping change. It would give NIJ more authority and responsibility, the discharge of which would require more resources-i. e., funding. Authorizing legislation should consider possible conflicts of jurisdiction, especially with OSHA. If OSHA undertook to require police officers to wear OSHA-approved armor, and if OSHA-approved armor were not NIJ-certified, a legal conflict would arise. However, OSHA has not expressed an intent to protect police by such a measure.

Enacting H.R. 322 would not settle the standards controversy and might exacerbate it. We do not know whether the Act would save more lives than the current regime of voluntary compliance with the NIJ standard. Purchasers could have confidence that armor sold after the law was in force would be very safe, as NIJ-certified armor is now. The question is whether it would be purchased and worn as much as some non-NIJ-certiiled armor, which some customers prefer because of comfort or cost. We do not know the answer to this question, but it should not be dismissed; uncertified armor has also performed well in service and has saved many lives.

Enacting H.R. 322 would require manufacturers to submit representative samples of certified models of armor to NIJ periodically to be tested for continued compliance. That is, H.R. 322 would create a mandatory quality-control program. It does not specify details of the sampling and testing; it leaves that to NIJ. NIJ has not yet proposed or specified details, so it is not yet possible to assess the effectiveness of the quality-control provisions of the bill. Enacting H.R. 322 is not necessary to assure consumers that production units of NIJ-certified models conform to the units submitted for certification or have acceptable ballistic resistance. A voluntary quality-control program would suffice for that.

Fund Expanded FTC Activity

Congress could fund expanded FTC activity to investigate complaints of, and prosecute cases of, false or deceptive advertising or labeling of armor. This may be necessary if complaints increase--e.g., if more vigorous enforcement by NIJ uncovers more evidence of such malfeasance.

Fund an OSHA program To Standardize Armor and Mandate Wearing

Congress could fund an OSHA program to standardize armor and mandate wearing. The Administration could propose such a program, or the Congress could require the Administration to do so.

@- Occupational Safety and Health Act of 1970, 29 U.S.C. 651 et seq.